

First Direct Two-Sided Bound on the Bs Oscillation Frequency

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On behalf of the DØ Collaboration

Joint Experimental Theoretical Seminar

“Wine & Cheese”

3/24/06

FNAL



Outline

- Motivation**
- Detector**
- Analysis Outline**
- Analysis Details**
- Results**
- Conclusion**

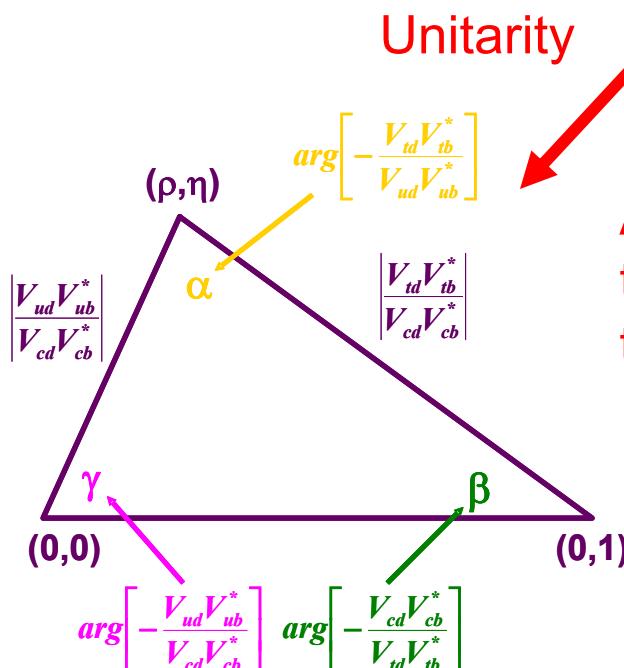


Motivation

□ Standard Model Lagrangian

$$L = \frac{g}{\sqrt{2}} \overline{(u, c, t)}_L V_{CKM} \gamma_\mu \begin{pmatrix} d \\ s \\ b \end{pmatrix}_L W^\mu + h.c.$$

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \approx \begin{pmatrix} 1 - \frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda(1 + iA^2\lambda^4\eta) & 1 - \frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1 - \rho - i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

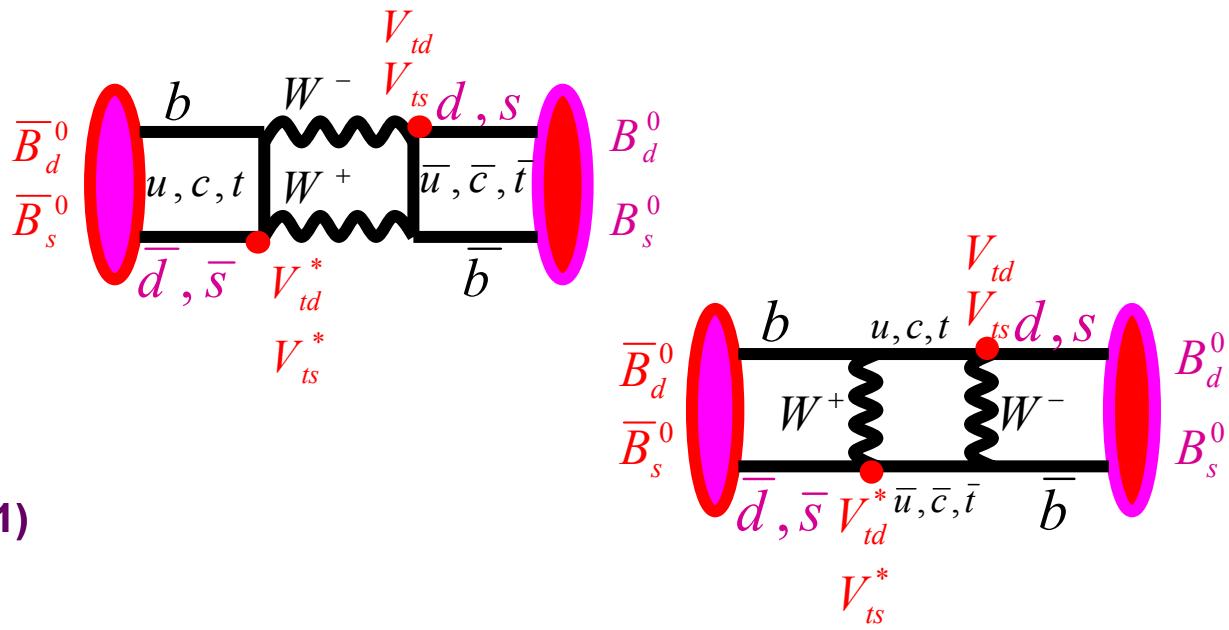
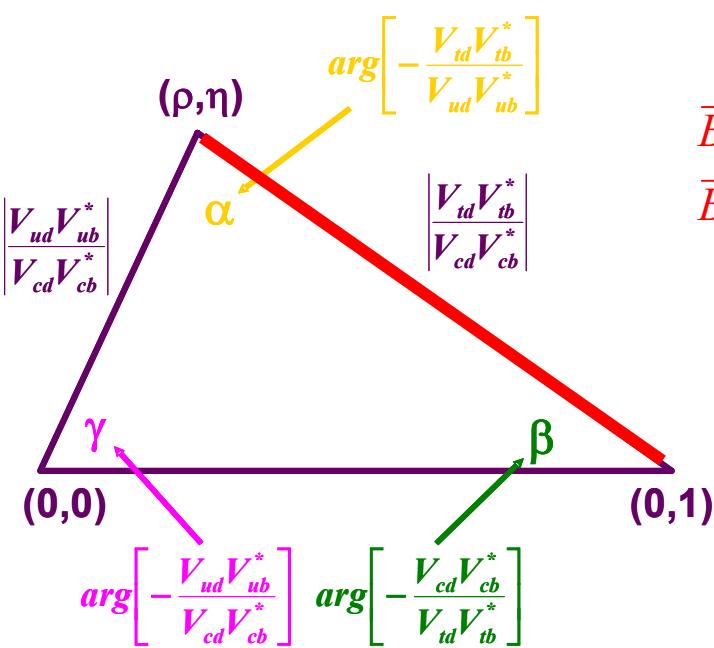


Area of the Unitarity Triangle is proportional to the CP violation in the Standard Model due to CKM Matrix

Sides and angles of the Triangle could be determined using many physics processes → Consistency check



Triangle Side From B Mixing



B_d oscillation frequency $\Delta m_d = \left| V_{tb}^* V_{td} \right|^2 \cdot (QCD \text{ parameters})$

Cancellation of many QCD parameters in ratio

$$\frac{\Delta m_s}{\Delta m_d} \propto \left| \frac{V_{ts}}{V_{td}} \right|^2$$

→ Determination of V_{td} with much better precision



$B - \bar{B}$ Mixing and Oscillations

$$|B_1\rangle = \frac{1}{\sqrt{2}} (|B^0\rangle + |\bar{B}^0\rangle) = |B_H\rangle$$

$$|B_2\rangle = \frac{1}{\sqrt{2}} (|B^0\rangle - |\bar{B}^0\rangle) = |B_L\rangle$$

Mass Eigenstates
(and CP eigenstates
if ignore CP violation)

Weak Eigenstates

$$\hat{H} \begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix} = \begin{pmatrix} M - \frac{i\Gamma}{2} & M_{12} - \frac{i\Gamma_{12}}{2} \\ M_{12}^* - \frac{i\Gamma_{12}^*}{2} & M - \frac{i\Gamma}{2} \end{pmatrix} \begin{pmatrix} B^0 \\ \bar{B}^0 \end{pmatrix}$$

- Then B_1 and B_2 are eigenstates with

masses: $m_{1,2} = M \pm \frac{\Delta m}{2}$ and lifetimes: $\Gamma_{1,2} = \Gamma \pm \frac{\Delta \Gamma}{2}$



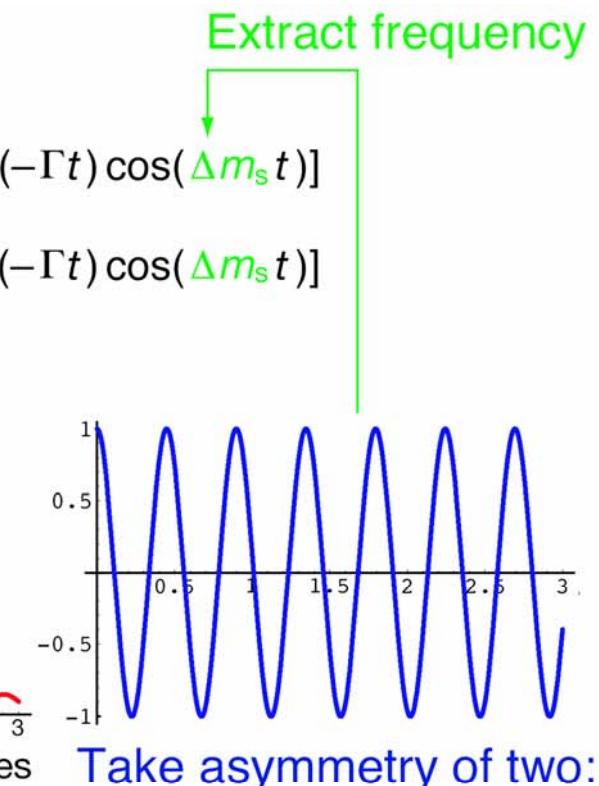
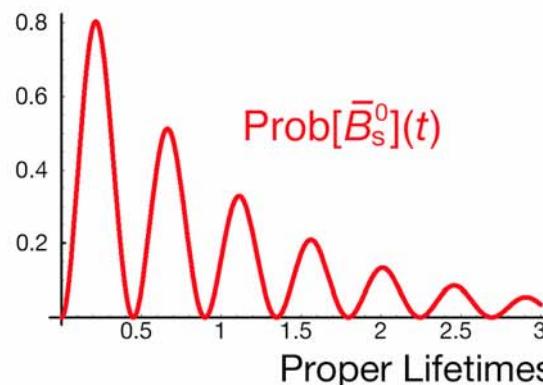
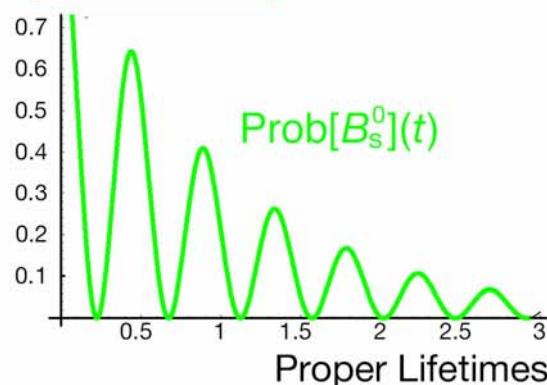
$B - \bar{B}$ Mixing and Oscillations

- If initially start with a B_s^0

$$\text{Prob}[B_s^0](t) = \frac{1}{4} [\exp(-\Gamma_1 t) + \exp(-\Gamma_2 t) + 2\exp(-\Gamma t) \cos(\Delta m_s t)]$$

$$\text{Prob}[\bar{B}_s^0](t) = \frac{1}{4} [\exp(-\Gamma_1 t) + \exp(-\Gamma_2 t) - 2\exp(-\Gamma t) \cos(\Delta m_s t)]$$

- For B_s^0



- What we get from it: $\Delta m_s \propto |V_{tb}^* V_{ts}|^2$

$$\Delta m_d \propto |V_{tb}^* V_{td}|^2$$

\uparrow \uparrow
 ~ 1 tiny

$$\Delta m_s \propto |V_{tb}^* V_{ts}|^2$$

\uparrow \uparrow
 ~ 1 still small, but larger than V_{td}

$$A = \frac{N[B^0](t) - N[\bar{B}^0](t)}{N[B^0](t) + N[\bar{B}^0](t)}$$

$$A \propto \cos(\Delta m_s t)$$



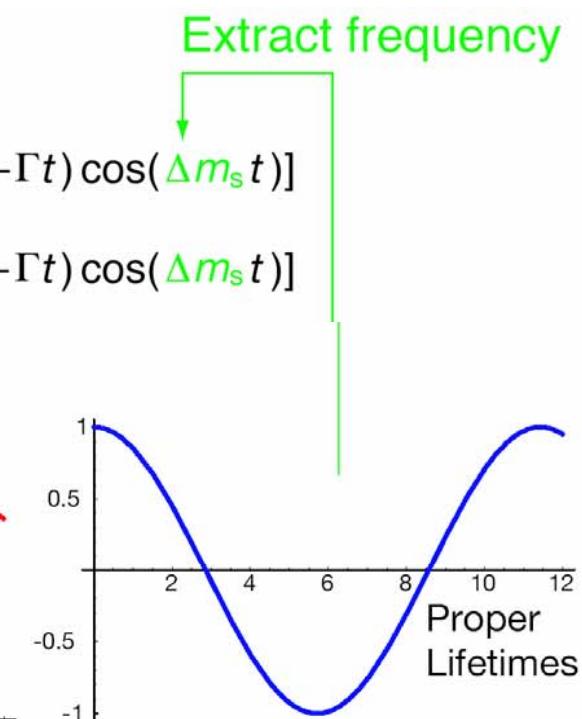
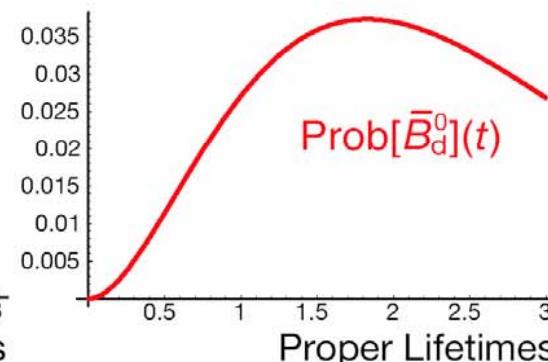
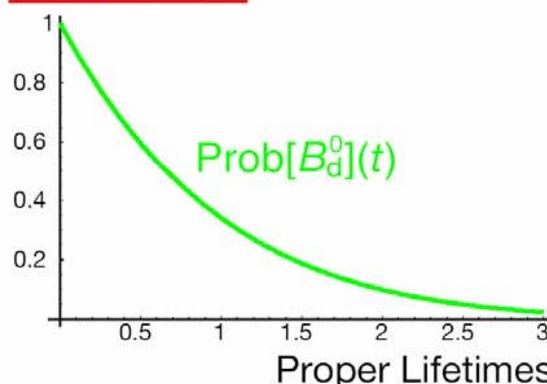
$B - \bar{B}$ Mixing and Oscillations

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- For B_d^0



Take asymmetry of two:

$$A = \frac{N[B^0](t) - N[\bar{B}^0](t)}{N[B^0](t) + N[\bar{B}^0](t)}$$

$$A \propto \cos(\Delta m_s t)$$

- What we get from it: $\Delta m_s \propto |V_{tb}^* V_{ts}|^2$

$$\Delta m_s \propto |V_{tb}^* V_{ts}|^2$$

\uparrow \uparrow
 ~ 1 tiny

\uparrow \uparrow
 ~ 1 still small, but larger than V_{td}



DØ Bs Mixing: from Simple to Complex

2003

- *Reconstruction of semileptonic B decays:
 $\mu D^0, \mu D^{*\pm}, \mu D^\pm, \mu D_s$*
- *Understanding of sample composition, resolution,
K-factor (momentum of non-reconstructed particles)*

2004

- *Measurements of Bd oscillations*
 - ✓ Opposite-side muon tagging for Moriond 2004
 - ✓ Same-side tagging and combined tagging for ICHEP 2004

2005

- *First Bs mixing results*
 - ✓ For Moriond 2005
 - ✓ Update in Summer 2005

2006

- *Increased statistics*
- *Improved initial state flavor tagging*
 - ✓ Added opposite-side electron tagging
- *Improved analysis technique*
- *First indication of the Bs oscillations signal presented at Moriond 2006*

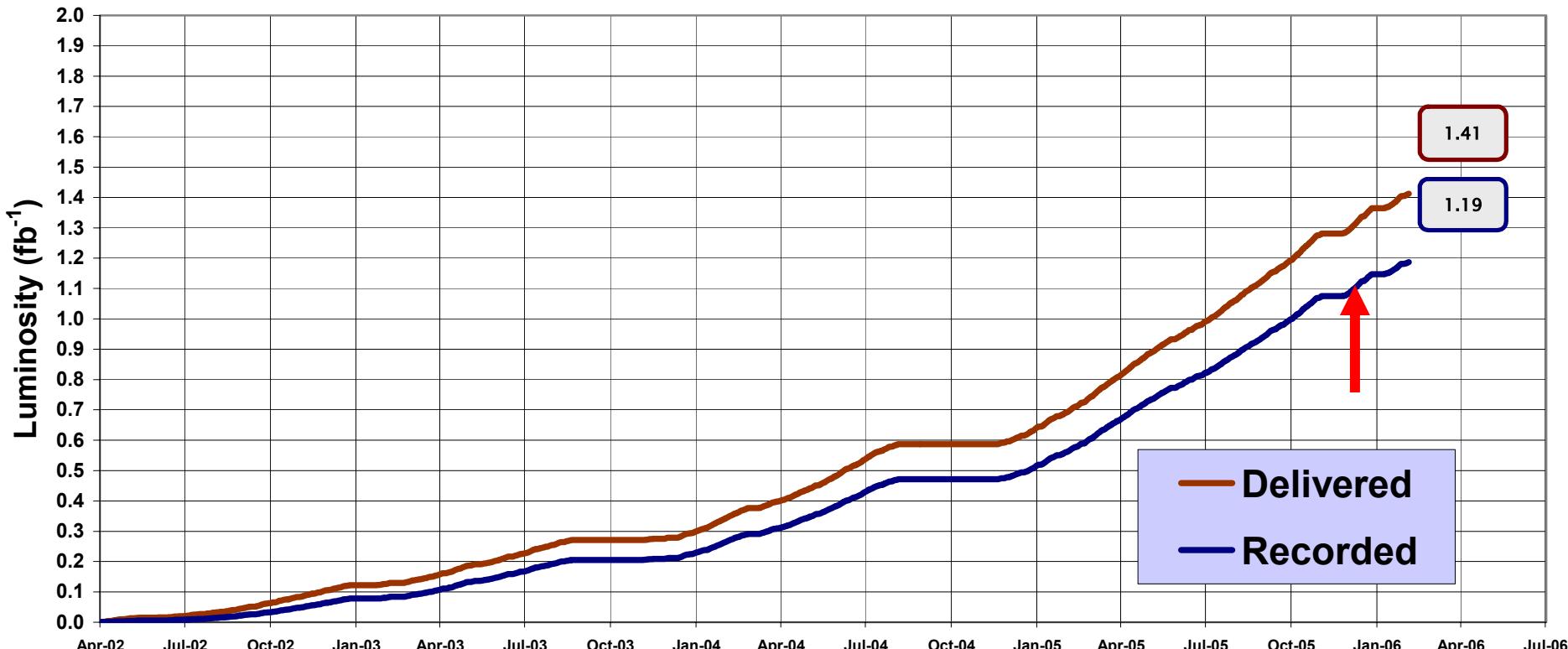


Excellent Tevatron Performance



Run II Integrated Luminosity

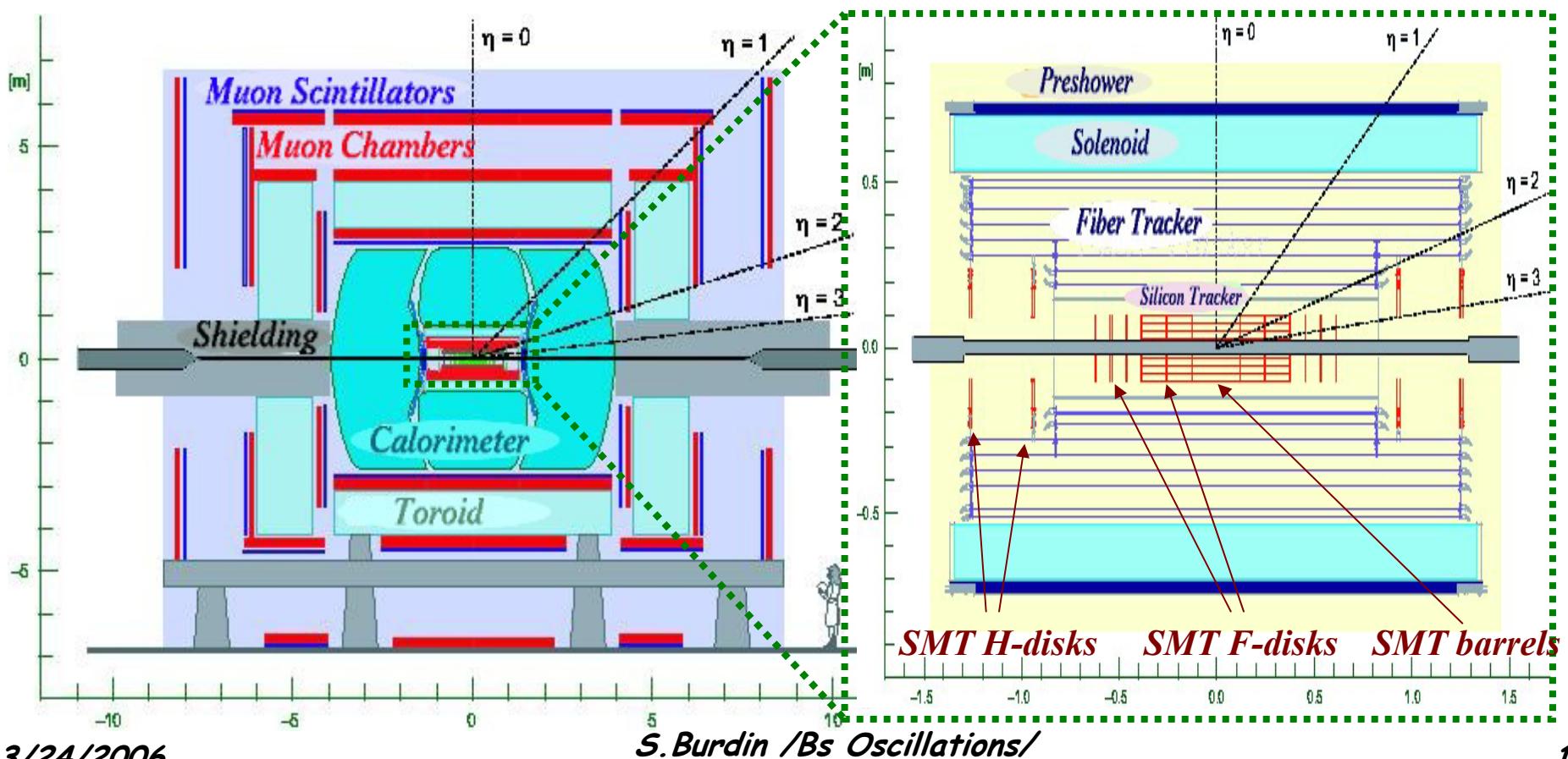
19 April 2002 - 22 February 2006



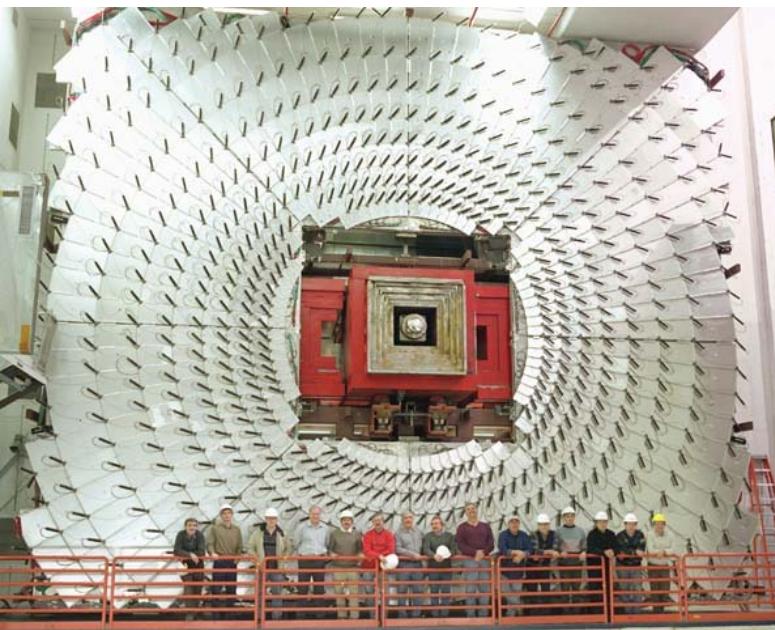
- Data sample corresponding to over 1 fb^{-1} of the integrated luminosity used for the B_s mixing analysis
- Full dataset is ready

DZero Detector

- Spectrometer : Fiber and Silicon Trackers in 2 T Solenoid
- Energy Flow : Fine segmentation liquid Ar Calorimeter and Preshower
- Muons : 3 layer system & absorber in Toroidal field
- Hermetic : Excellent coverage of Tracking, Calorimeter and Muon Systems



Muon Triggers



□ Single inclusive muons

- $|\eta| < 2.0, p_T > 3, 4, 5 \text{ GeV}$
- Muon + track match at Level 1
- No direct lifetime bias
 - ✓ Still could give a bias to measured lifetime if cuts on decay length are imposed in offline
- Prescaled or turned off depending on inst. lumi.
- B physics triggers at all lumi's
 - ✓ Extra tracks at medium lumi's
 - ✓ Impact parameter requirements
 - ✓ Associated invariant mass
 - ✓ Track selections at Level 3

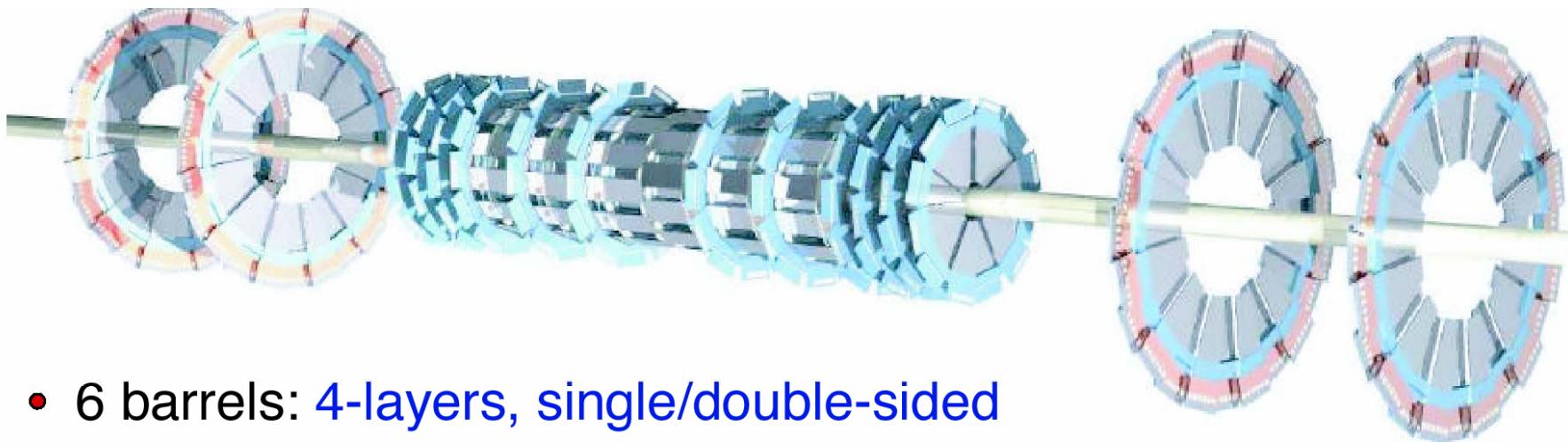
□ Dimuons: other muon for flavor tagging

□ e.g. at $50 \cdot 10^{-30} \text{ cm}^{-2}\text{s}^{-1}$

- 20 Hz of unbiased single μ
- 1.5 Hz of IP+ μ
- 2 Hz of di- μ

□ No rate problem at L1/L2

Silicon Microvertex Tracker (SMT)



- 6 barrels: 4-layers, single/double-sided
2/90 deg. stereo, radius: 2.7 – 10 cm
- 12 central F disks: double-sided, ± 15 deg. stereo
- 4 forward H disks: single-sided, ± 7.5 deg. stereo,
 $|z| = 1.2$ m, radius: 9.5 – 20 cm

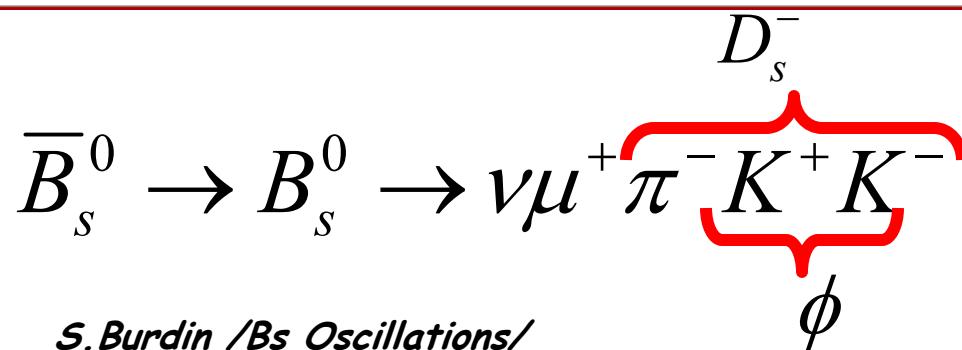
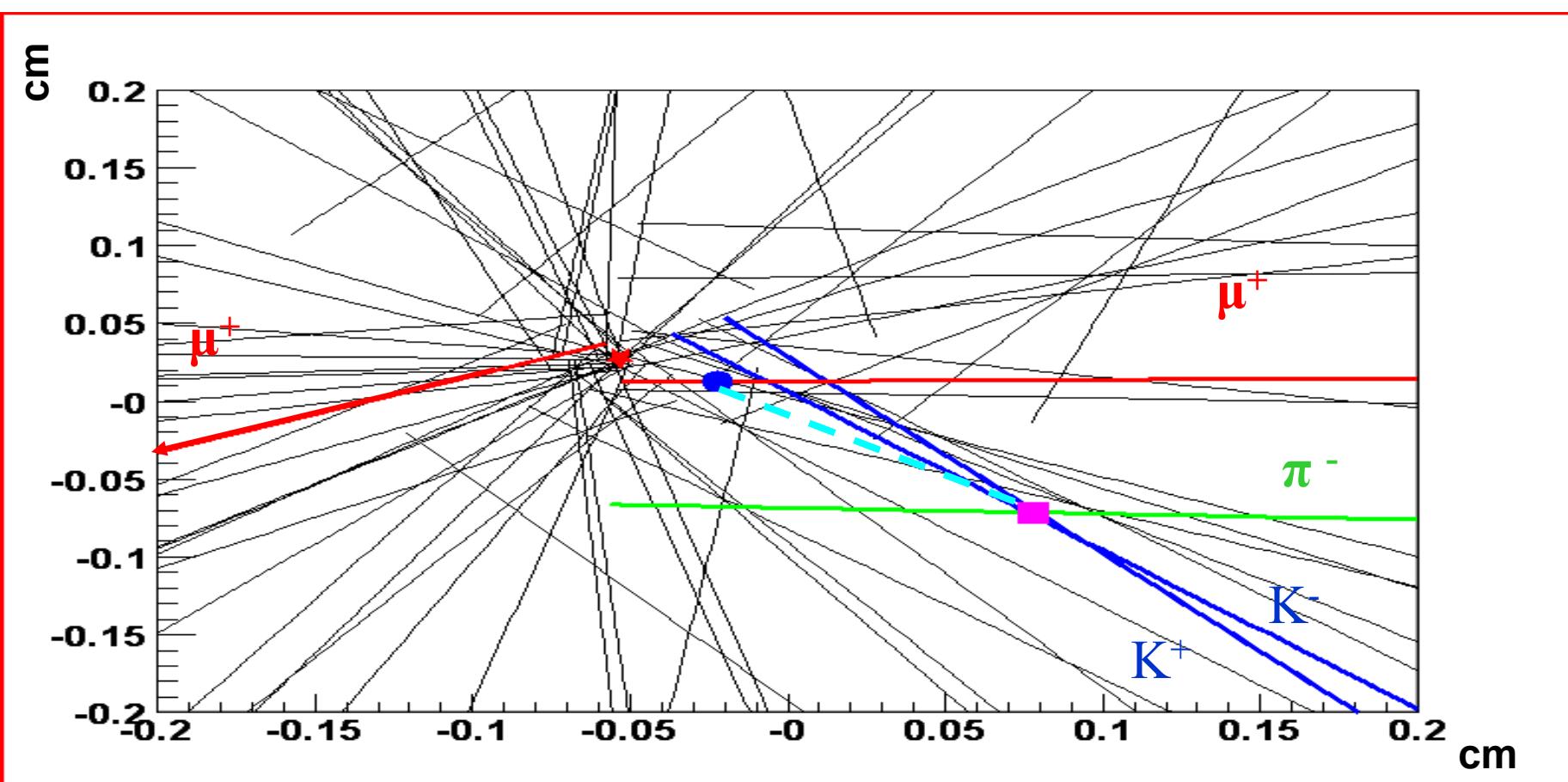
- Asymptotic (high momentum) resolution of $15\mu\text{m}$
 - Will be improved with Layer 0

Layer 0 is being inserted!

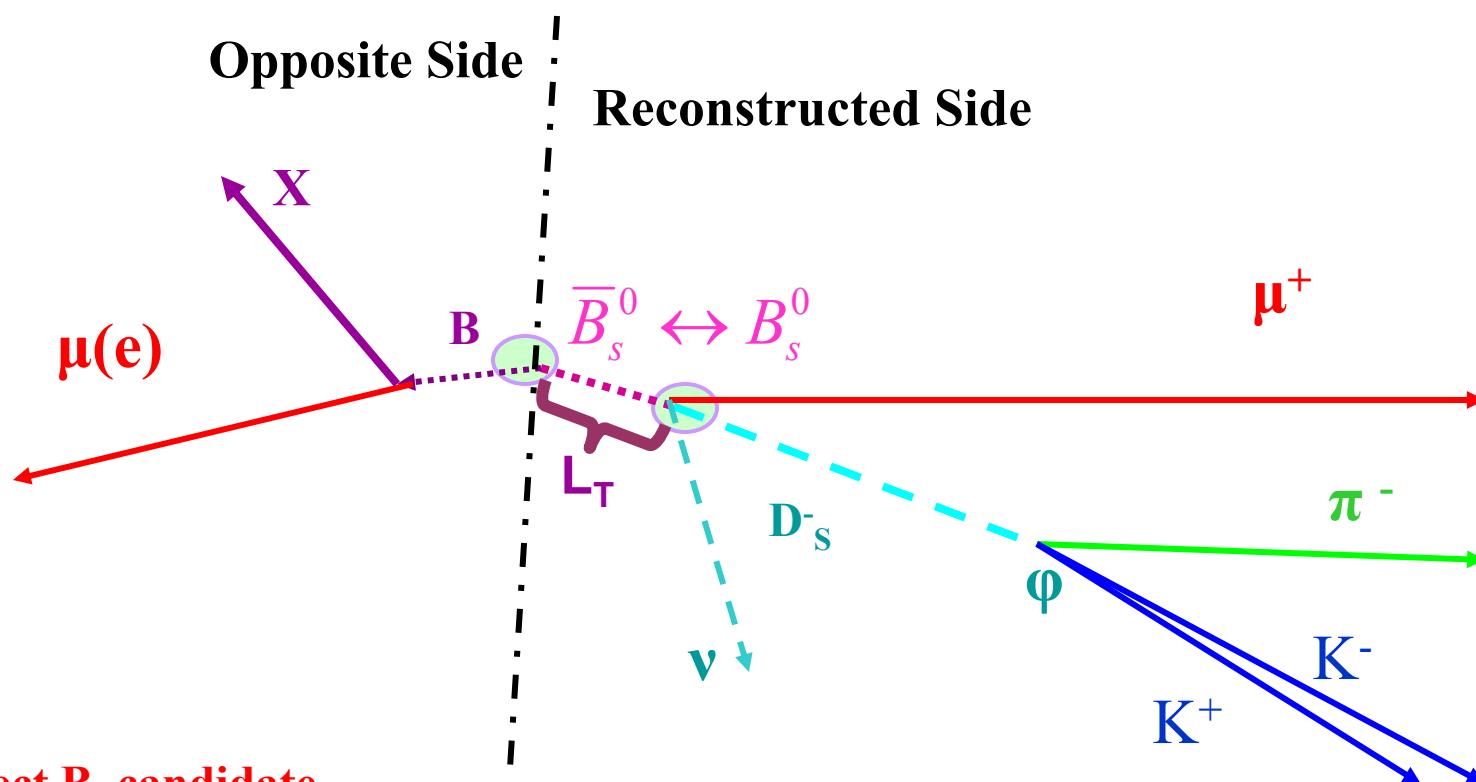


S.Burdin /Bs Oscillations/

Challenge: High Track Multiplicity

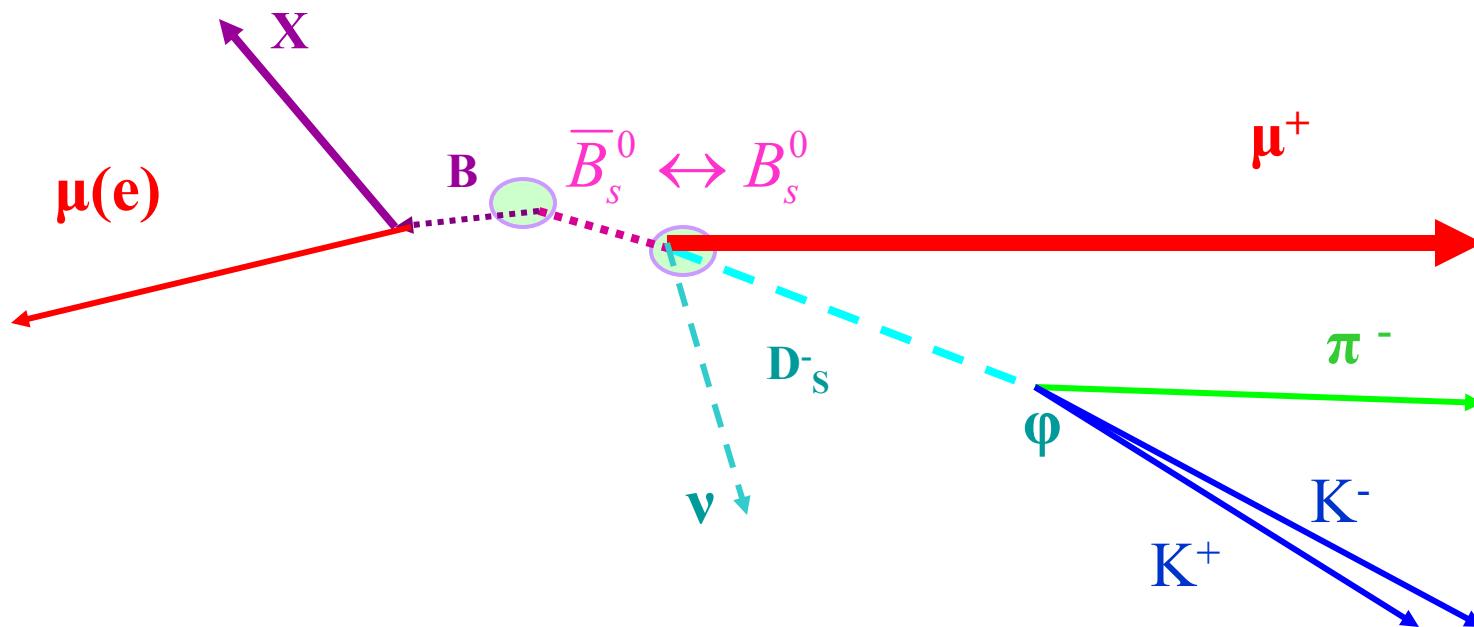


Analysis Outline



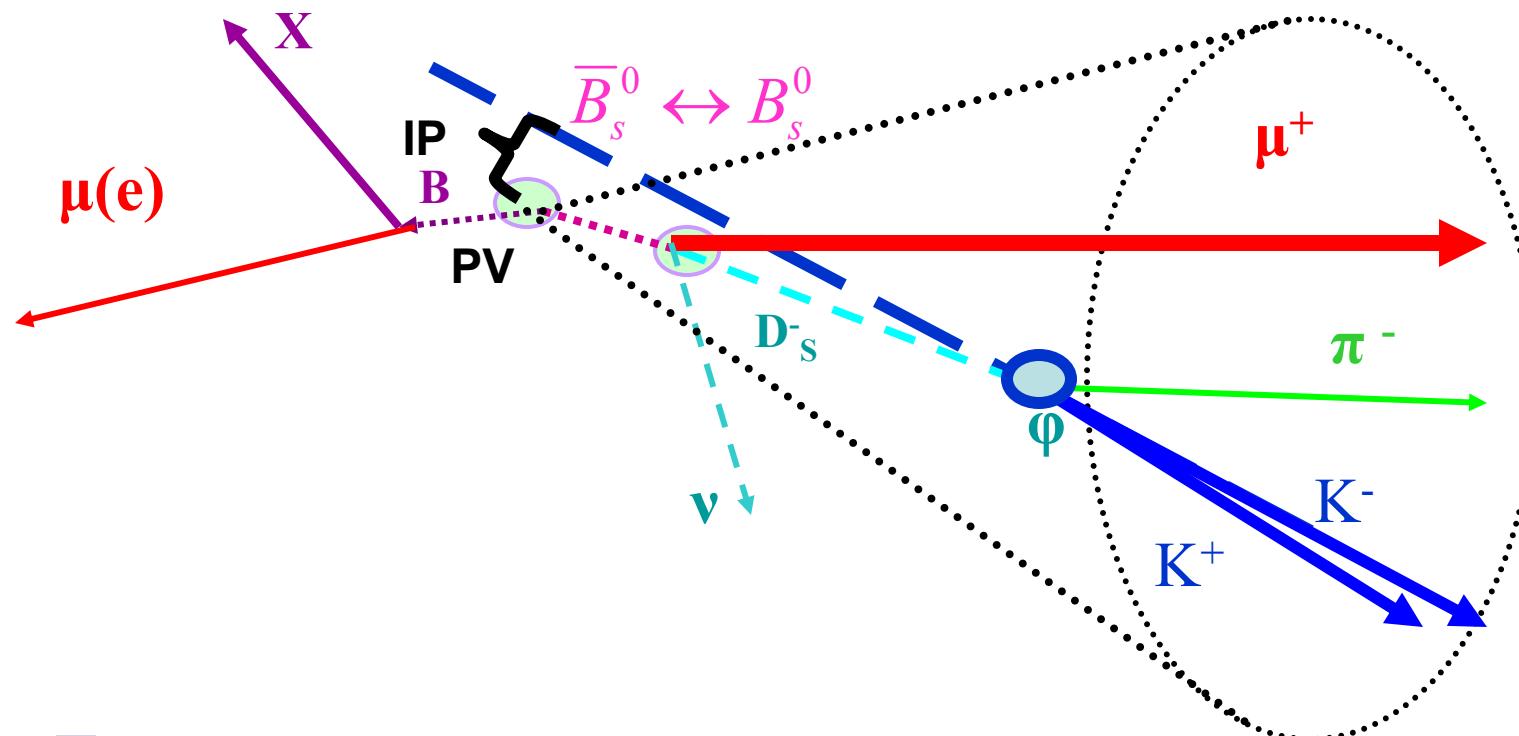
- Select B_s candidate**
 - Concentrate on the most clean decay mode $B_s \rightarrow \nu \mu D_s (\rightarrow \phi \pi)$
- For each B_s candidate**
 - B_s flavor at decay time from muon sign at the reconstructed side
 - Transverse length L_T and its error
 - Transverse momentum $P_T(B_s)$ (use $P_T(D_s \mu)$)
 - B -hadron flavor at the opposite side (indicates B_s flavor at production time)

Signal Selection



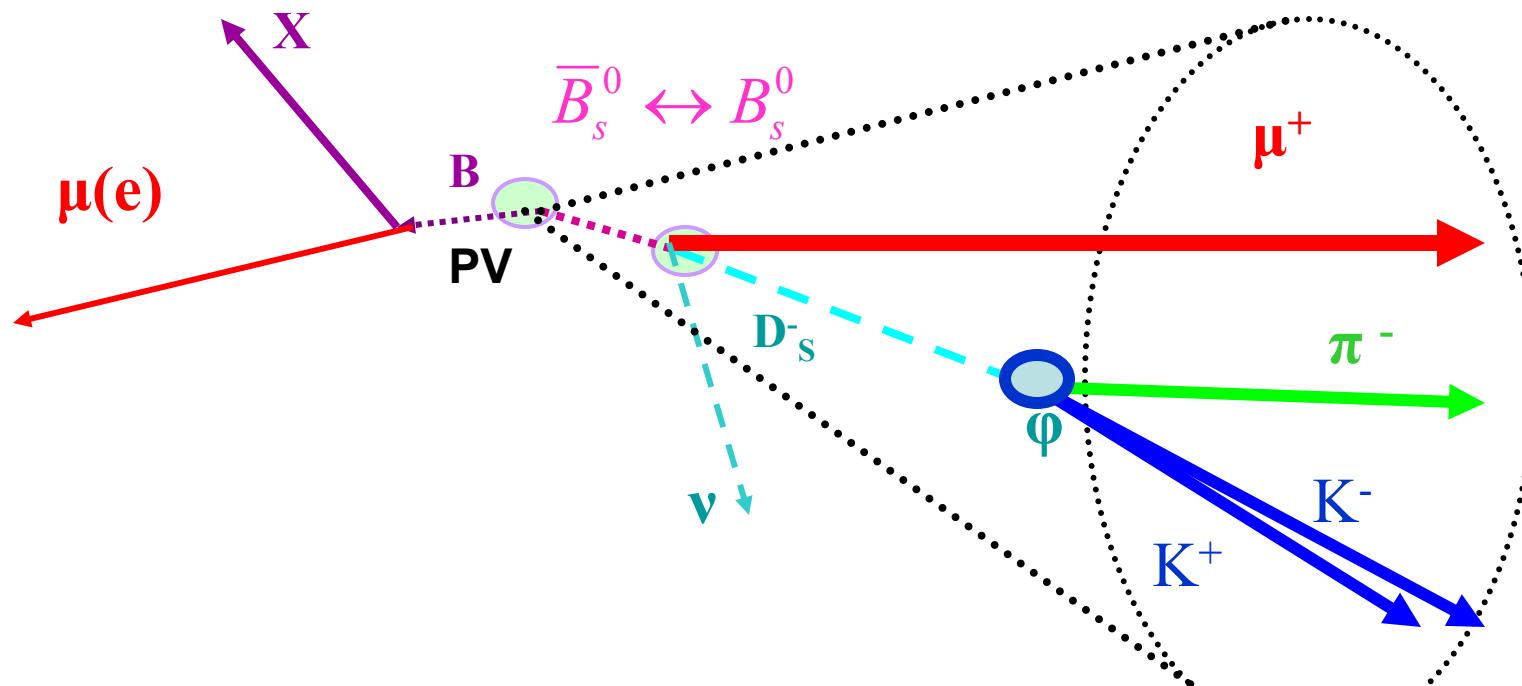
Select events with a muon

Signal Selection



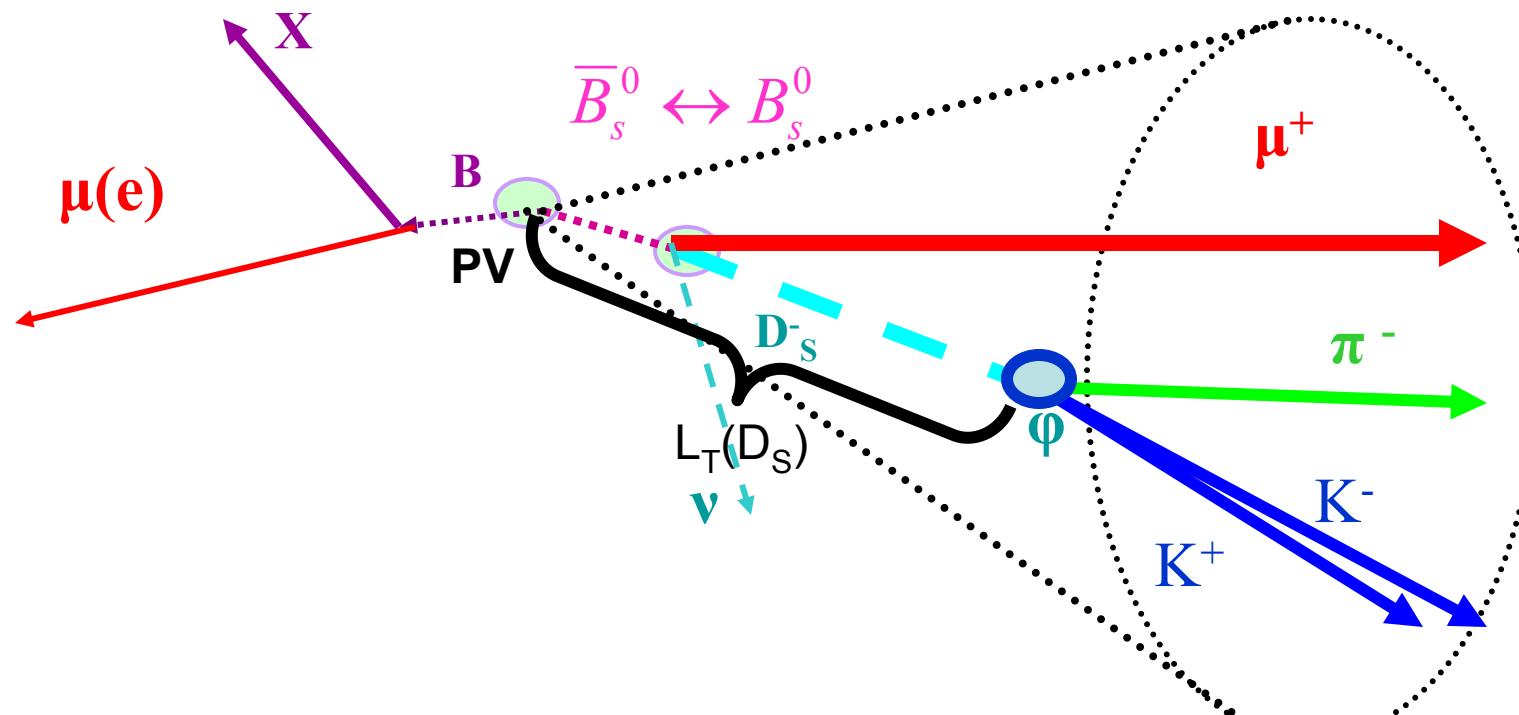
- Find two tracks in the same jet with the muon
 - different signs
 - Impact Parameter significances with respect to the Primary Vertex
 - common vertex
 - φ mass

Signal Selection



- Find third track in the same jet with the muon
 - sign opposite to the muon
 - Impact Parameter significance with respect to the Primary Vertex
 - common vertex with kaons
 - D_s mass

Signal Selection



- **Combine three tracks into D_s particle**
 - *Decay Length significance with respect to the Primary Vertex*
 - *common vertex with the muon*
 - *some constraints on the μD_s invariant mass*

Signal Selection Function

Further improvement in S/B following initial vertex, lifetime & mass window cuts:

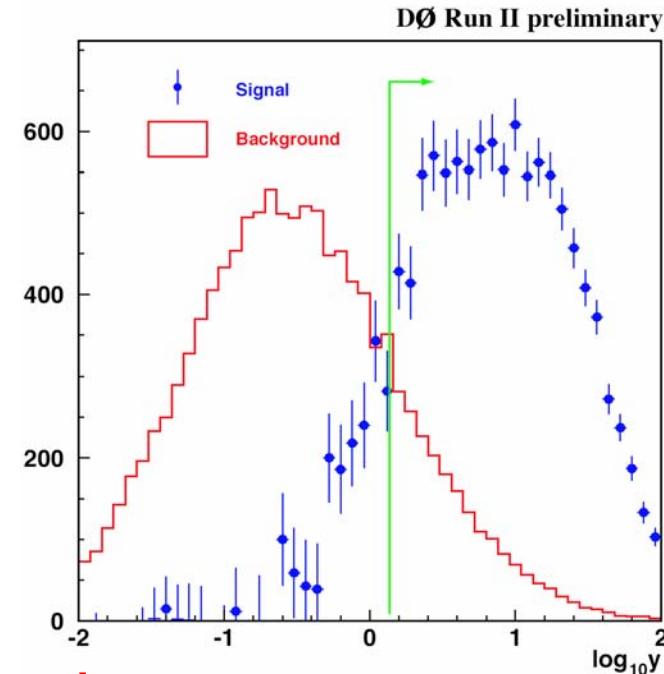
- Set of discriminating variables x_i constructed for each event
- Cut on combined variable, product of likelihood ratios

(PDFs for background and signal from data):

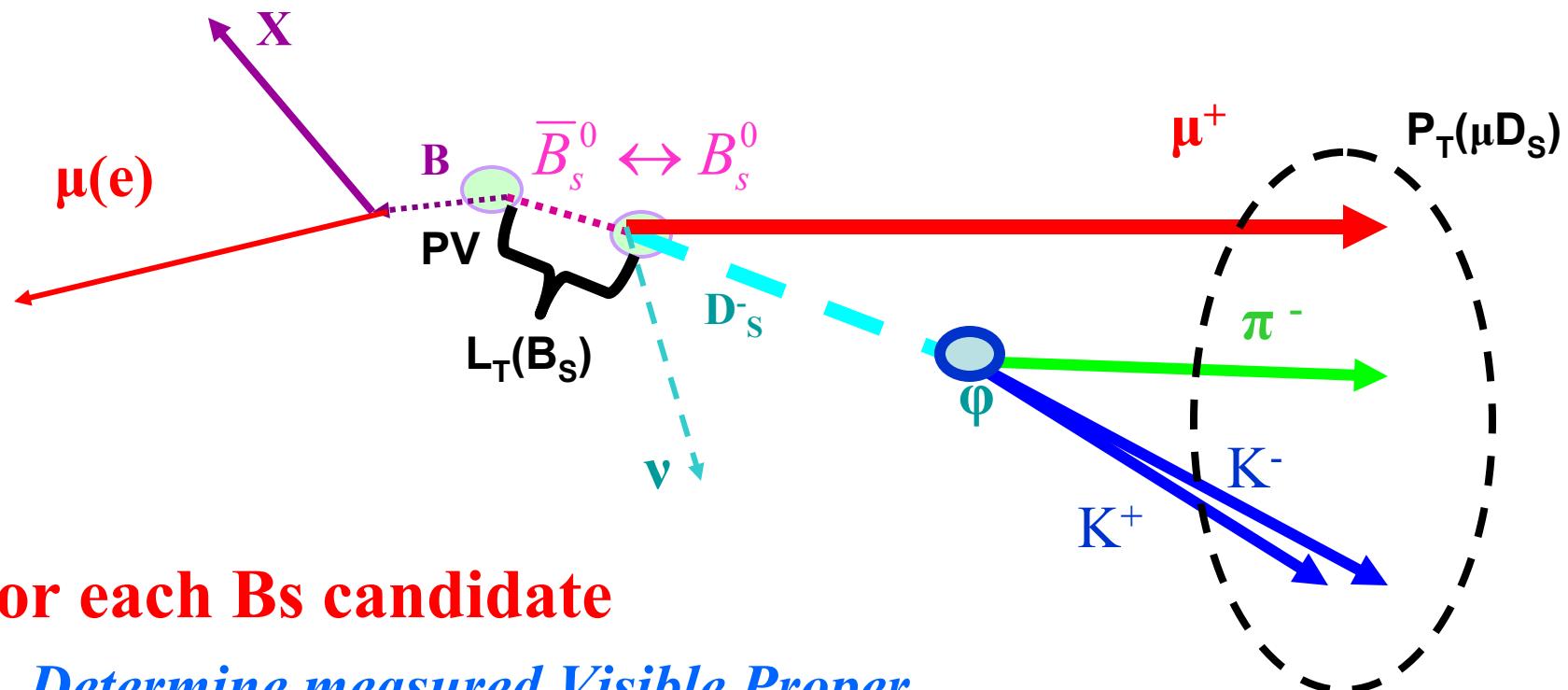
$$y = \prod_i^n y_i ; \quad y_i = \frac{PDF_i^s(x_i)}{PDF_i^b(x_i)}$$

The following discriminating variables were used:

- Helicity angle, defined as the angle between the D_s and K_1 momenta in the (K_1, K_2) center of mass system;
- Isolation, computed as $Iso = p^{tot}(\mu D_s) / (p^{tot}(\mu D_s) + \sum p_i^{tot})$. The sum $\sum p_i^{tot}$ was taken over all charged particles in the cone $\sqrt{(\Delta\phi)^2 + (\Delta\eta)^2} < 0.5$, where $\Delta\eta$ and $\Delta\phi$ are the pseudorapidity and the azimuthal angle with respect to the (μD_s) direction. The μ , K_1 , K_2 and π were not included in the sum;
- $p_T(K_1 K_2)$;
- Invariant mass, $M(\mu D_s)$;
- χ^2 of the D_s vertex fit;
- $M(K_1 K_2)$.



Signal Selection



❑ For each B_s candidate

- *Determine measured Visible Proper Decay Length*

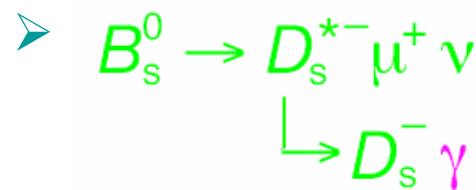
$$x^M = m_{B_s} \cdot \frac{\left(\vec{L}_T \cdot \vec{p}_T^{D_s\mu} \right)}{\left(p_T^{D_s\mu} \right)^2}$$

Proper Decay Length

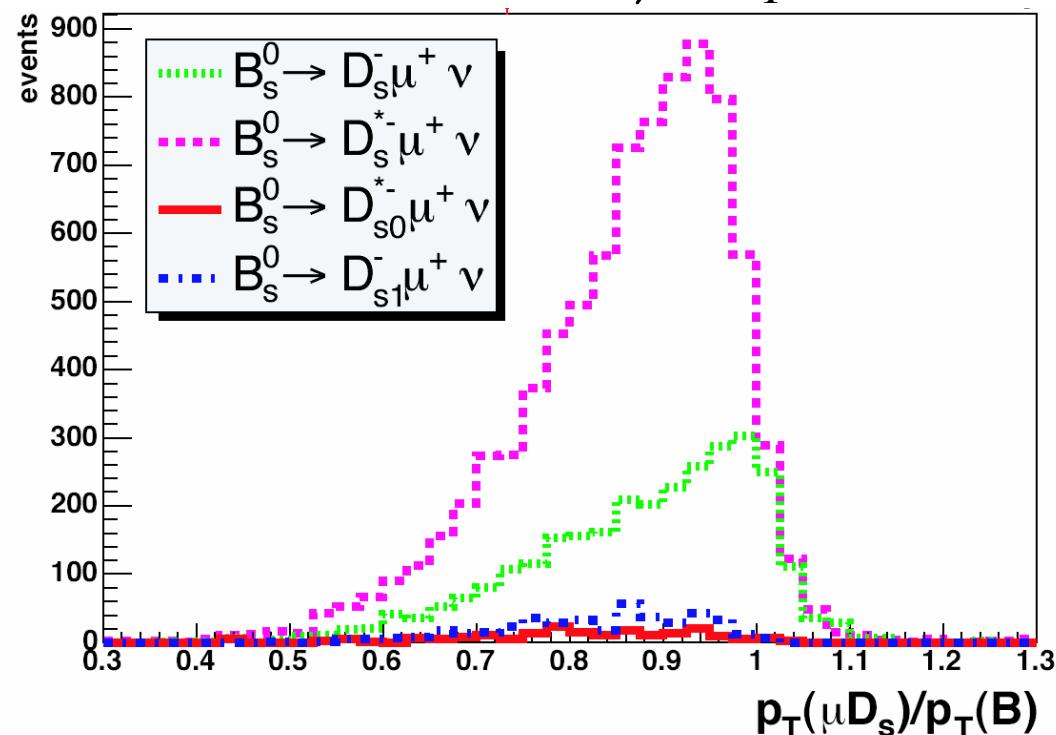
- Proper Decay Length is determined from the Visible Proper Decay Length

$$ct_{B_s} = x^M K$$

- K Factor takes into account the escaping neutrino and other missing particles

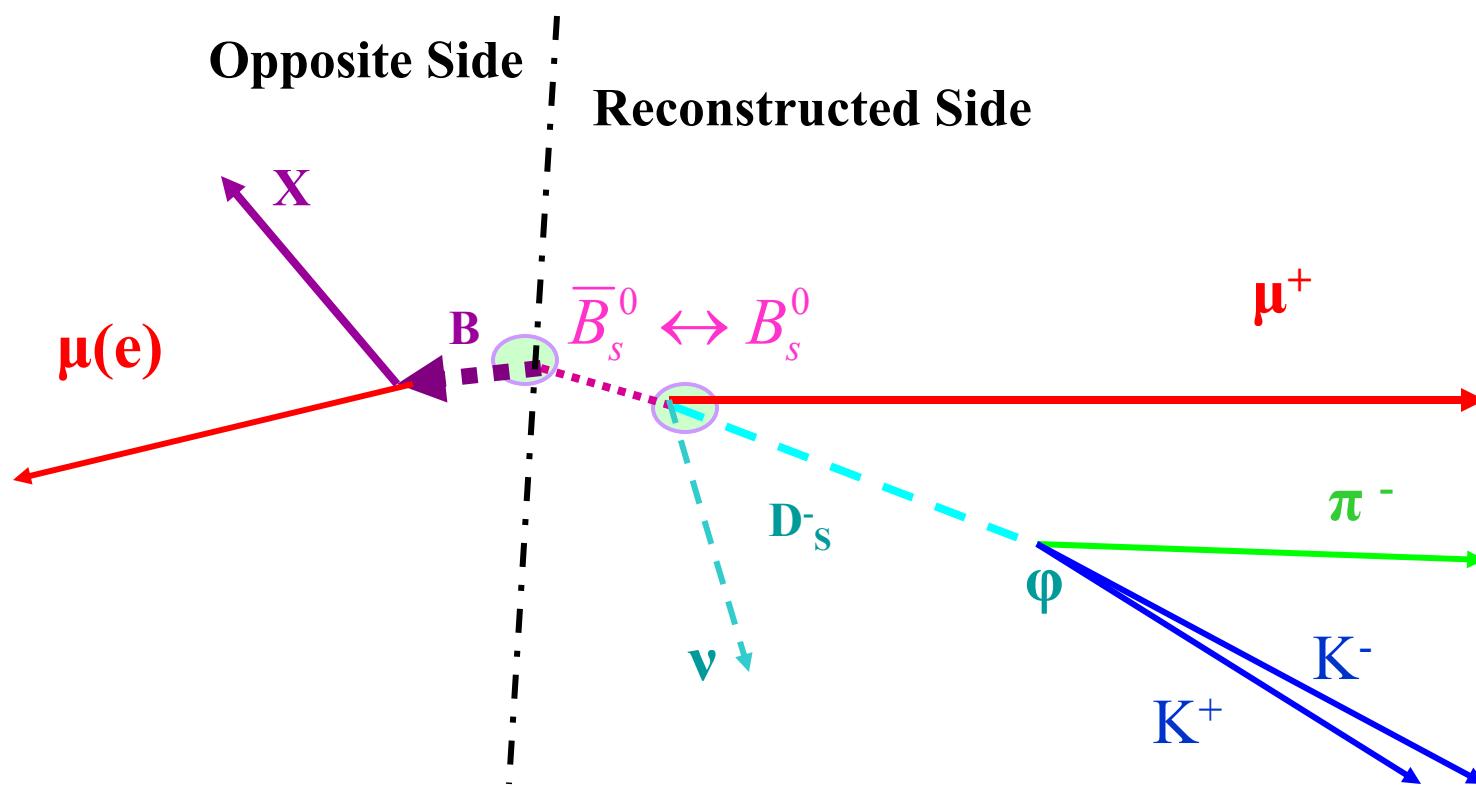


$$K = \frac{p_T^{D_s \mu}}{p_T^{B_s}}$$



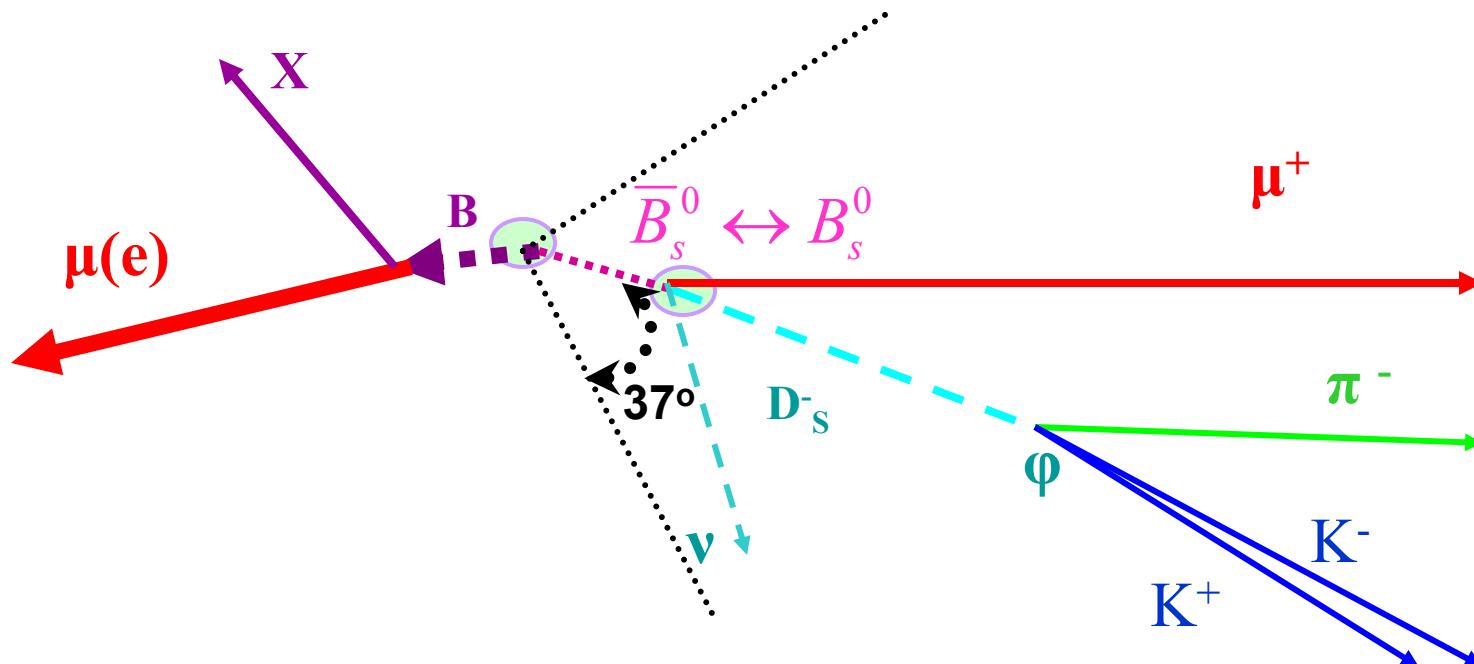
- From MC, each decay mode

Initial State Tagging



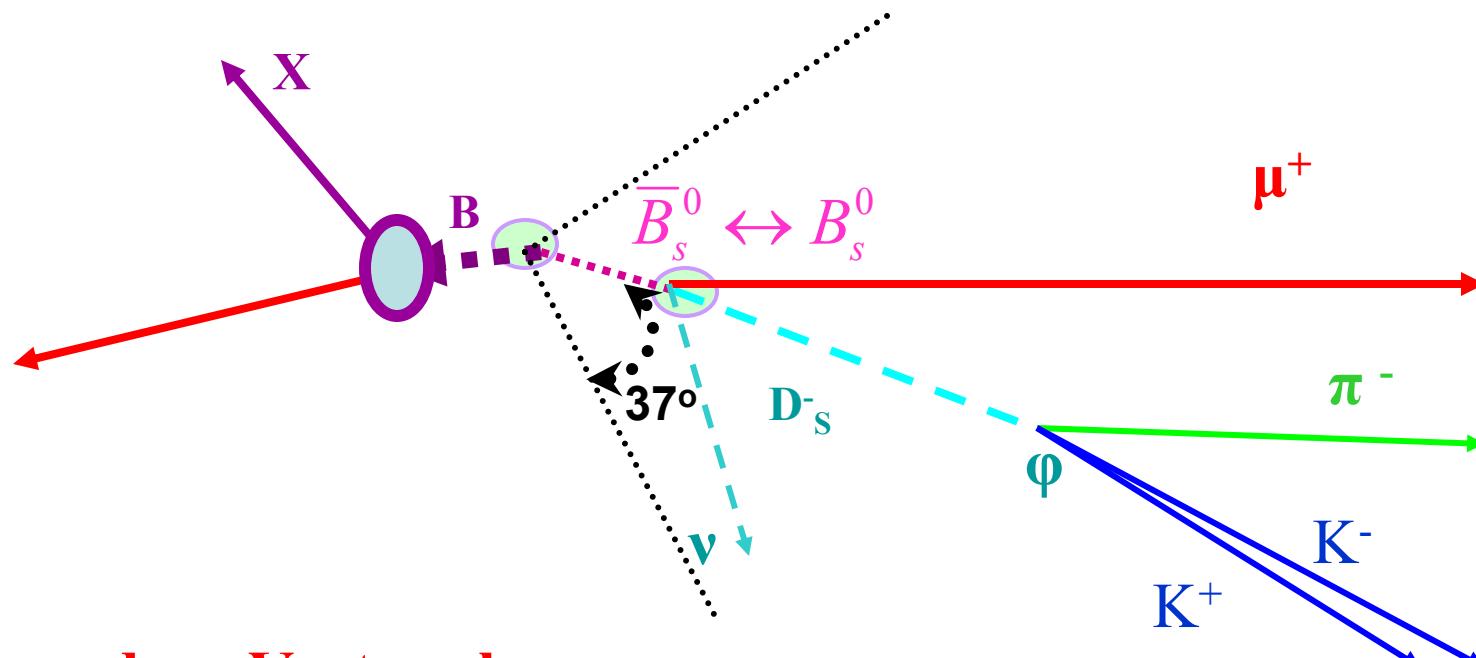
- Use Opposite Side B-hadron
 - $b\bar{b}$ pairs are produced

Initial State Tagging



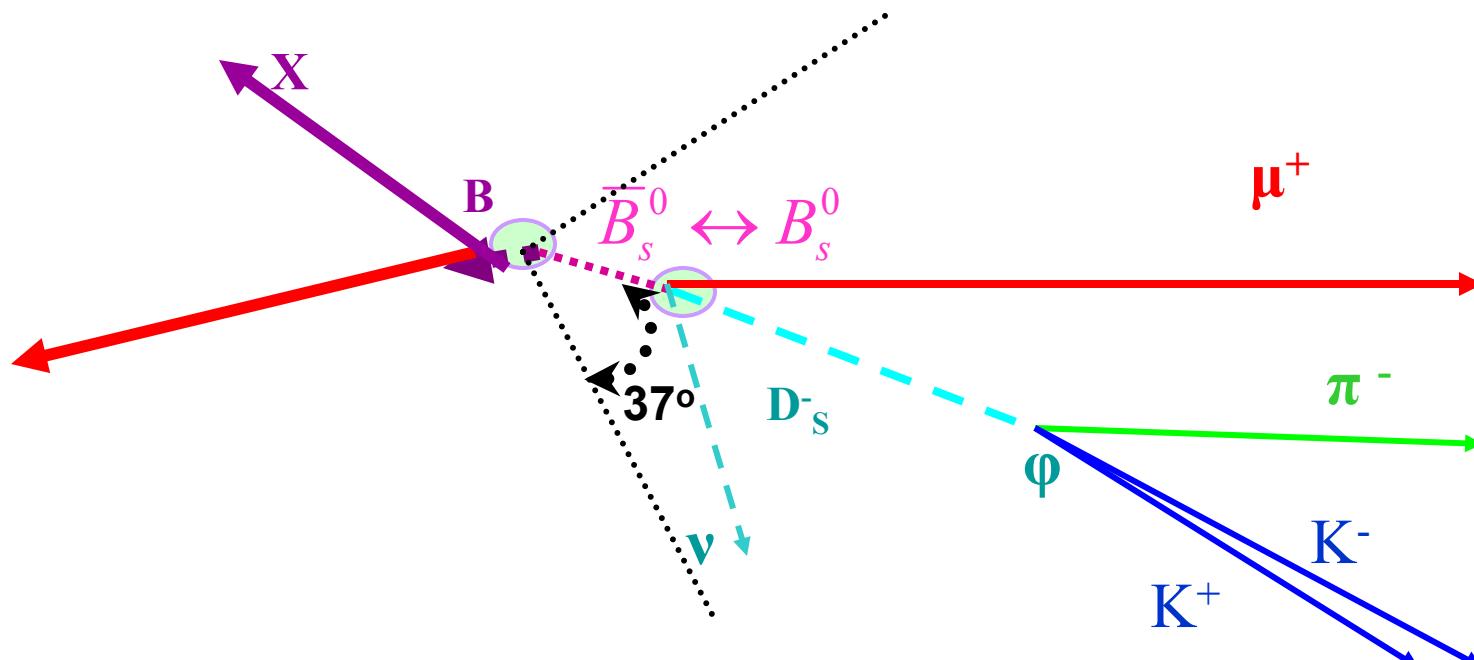
- If muon or electron at opposite side is found then use the muon (electron) jet charge
 - assume B semileptonic decays
 - clean from background (cascade decays) using weighting technique

Initial State Tagging



- Secondary Vertex charge
- Find Secondary Vertex at opposite side
 - formed by tracks with Impact Parameter significances with respect to the Primary Vertex
 - has decay length significance with respect to the Primary Vertex
- Sum weighted charges of tracks in this vertex

Initial State Tagging



Event Charge

➤ *Sum weighted charges of tracks with $p_T > 0.5 GeV$*



$$Q_{EV} = \frac{\sum p_T q}{\sum p_T}$$

Combination of Initial Flavor Tagging Variables

- Each flavor discriminating variable x_i as used described previously,

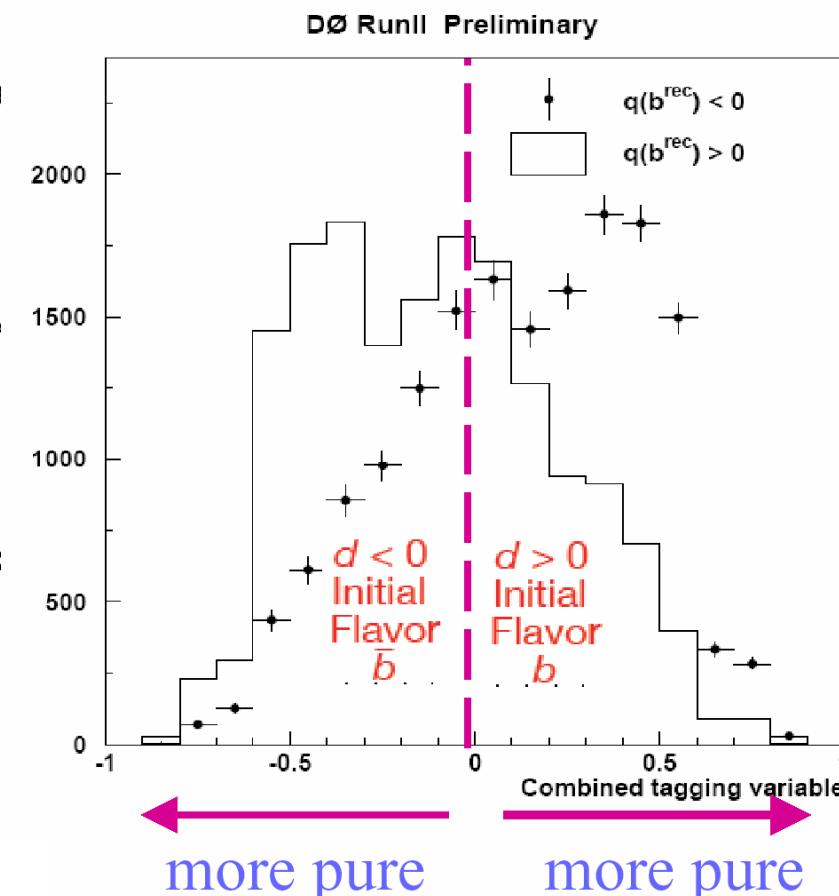
likelihood ratio:

$$y = \prod_i^n y_i ; \quad y_i = \frac{PDF_i^{\bar{b}}(x_i)}{PDF_i^b(x_i)}$$

From data,
 $B_d^0 \rightarrow D^{*-} \mu^+ \nu$
 wrong-sign subtracted,
 at short lifetimes
(non-oscillated)

- Form single flavor-tag variable

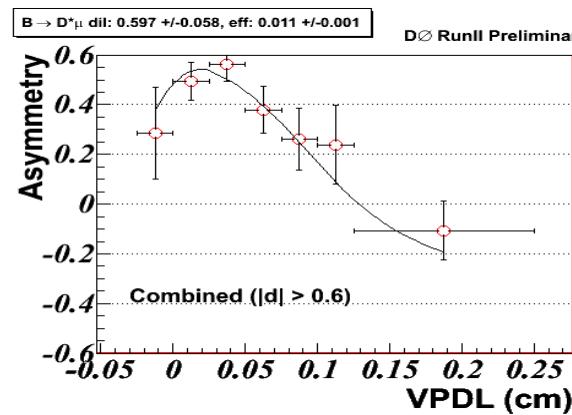
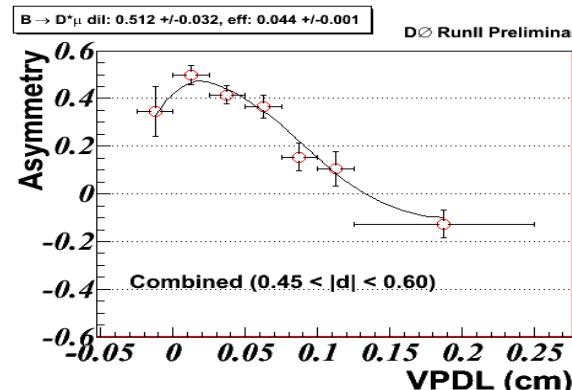
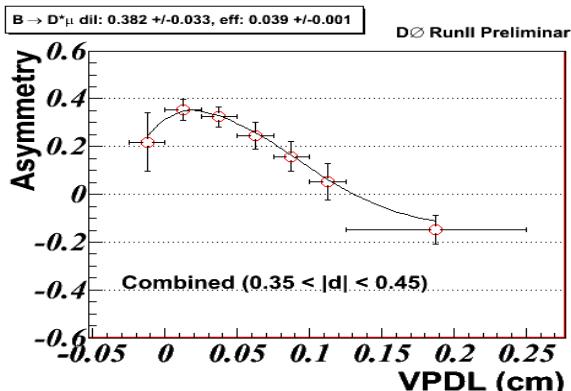
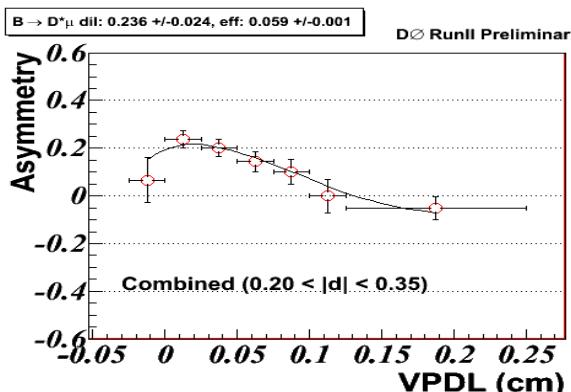
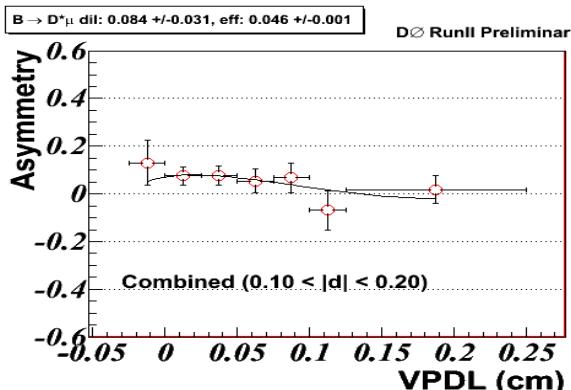
$$d = \frac{1-y}{1+y}$$





Calibration of Dilution Using $B_d \rightarrow D^{*\pm} \mu \nu X$

Increasing dilution



Increasing dilution

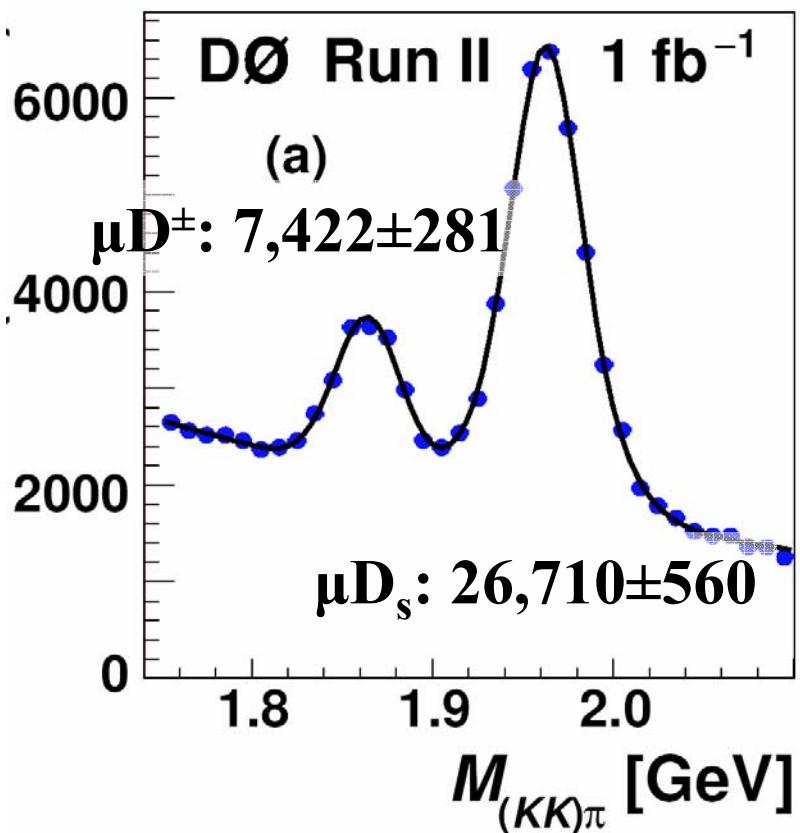
$$\Delta m = 0.506 \pm 0.020 \text{ (stat.) } ps^{-1}$$

$$\varepsilon D^2 = (2.48 \pm 0.21) \% \text{ (stat.)}$$

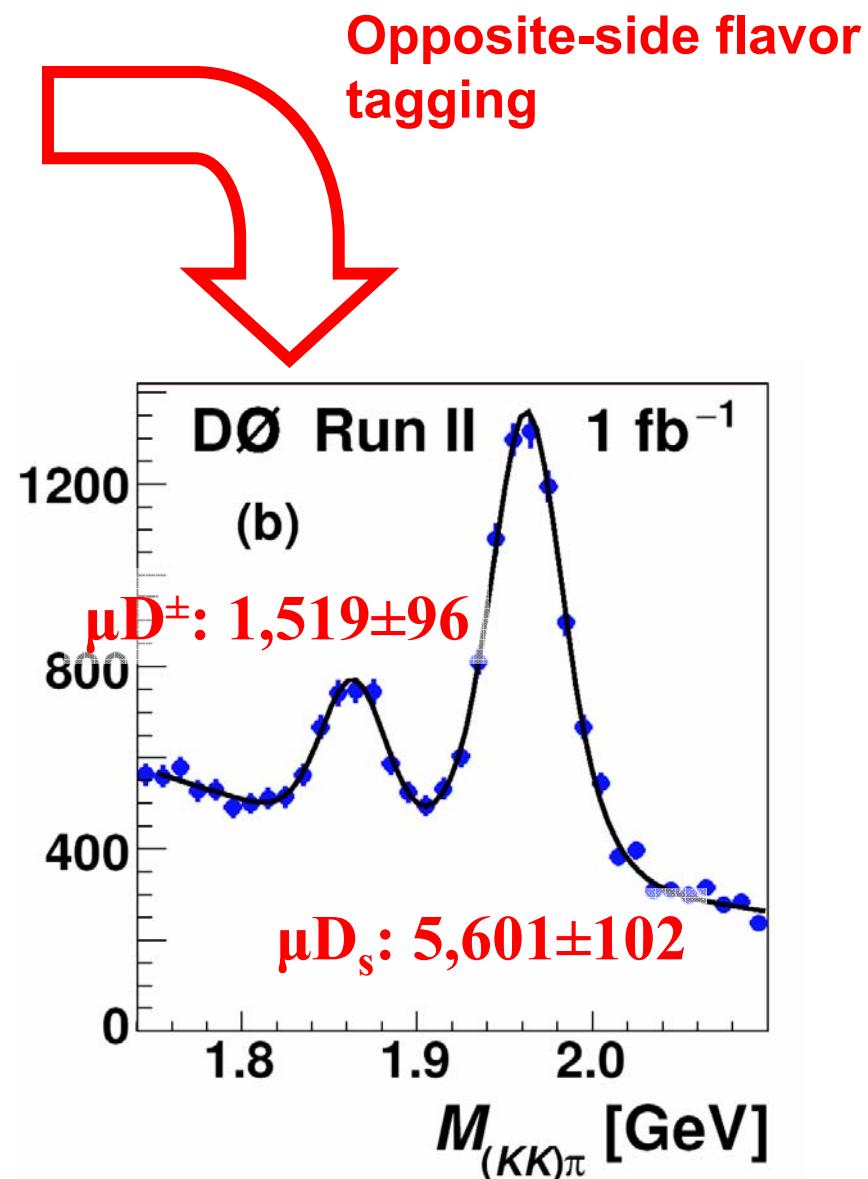
$$\varepsilon = (19.9 \pm 0.2) \% \text{ (stat.)}$$

$$\Delta m_{HFAG} = 0.507 \pm 0.004 \text{ ps}^{-1}$$

$\mu\phi\pi$ sample @ DØ ($\sim 1 \text{ fb}^{-1}$)



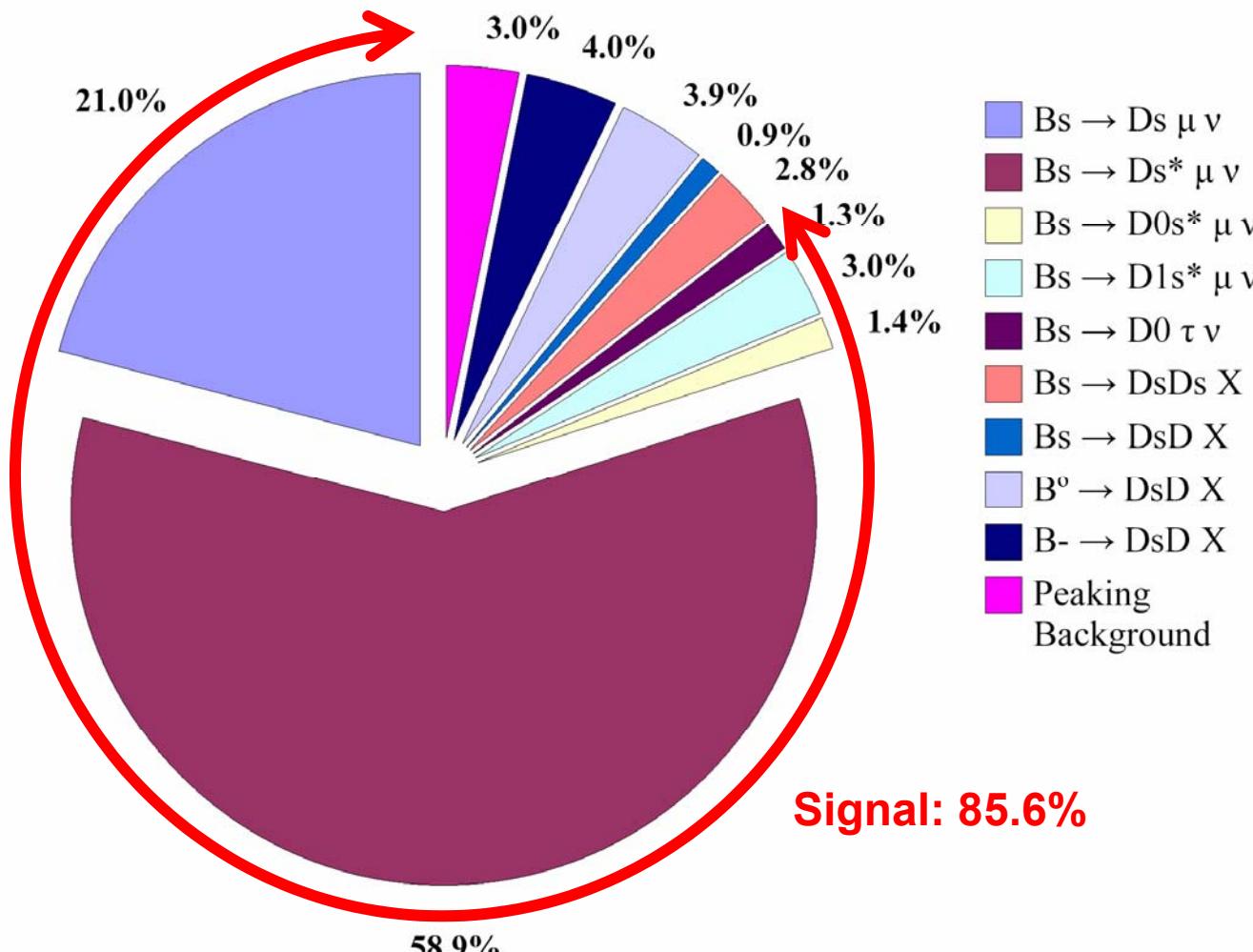
Tagging efficiency $\sim 20\%$



Sample Composition

The signal peak ($\mu + D_s$)

➤ Estimate using MC simulation, PDG Br's, Evtgen exclusive Br's





Expected Asymmetry

$$p_s^{nos/osc} = \frac{K}{c\tau_{B_s}} e^{-\frac{Kx}{c\tau_{B_s}}} \cdot 0.5 \cdot (1 \pm \mathcal{D} \cos(\Delta m_s \cdot Kx / c))$$

Efficiency

$$\varepsilon = \frac{N_{\text{total flav. tagged events}}}{N_{\text{total events}}}$$

Purity

$$\eta = \frac{N_{\text{correct flav. tagged events}}}{N_{\text{total flav. tagged events}}}$$

Dilution

$$\mathcal{D} = 2\eta - 1$$

(less than 1, \sim multiplier
of "ideal" ± 1 amplitude
of asymmetry)

$$\mathcal{D} = \mathcal{D}(d)$$

Effective flavor
tagging power

$$Signif = \sqrt{\frac{S\varepsilon\mathcal{D}^2}{2}} e^{-\frac{(\Delta m_s \sigma_\tau)^2}{2}} \sqrt{\frac{S}{S+B}}$$

Proper time
resolution



Amplitude Method

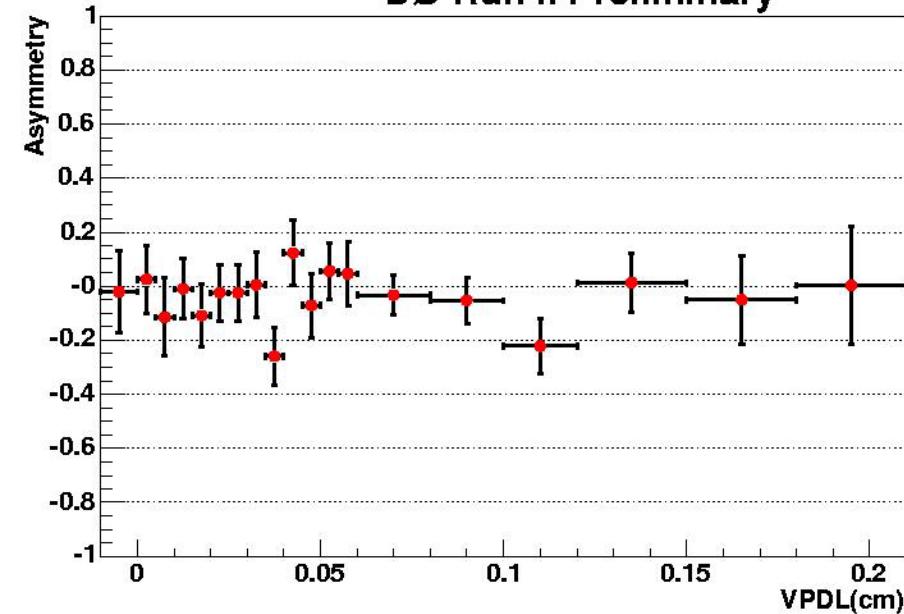
$$p_s^{nos/osc} = \frac{K}{c\tau_{B_s}} e^{-\frac{Kx}{c\tau_{B_s}}} \cdot 0.5 \cdot (1 \pm \mathcal{D} \cos(\Delta m_s \cdot Kx / c) \cdot \mathcal{A})$$


- If mixing signal with Δm_s , amplitude $\mathcal{A} = 1$
otherwise $\mathcal{A} = 0$
- Scan Δm_s , for each value find $\mathcal{A} \pm \Delta \mathcal{A}$
from the fit to the VPDL distributions
 - *fit to asymmetry vs. VPDL represents
a simplified case*



Binned Asymmetry Fit (Old technique)

DØ Run II Preliminary



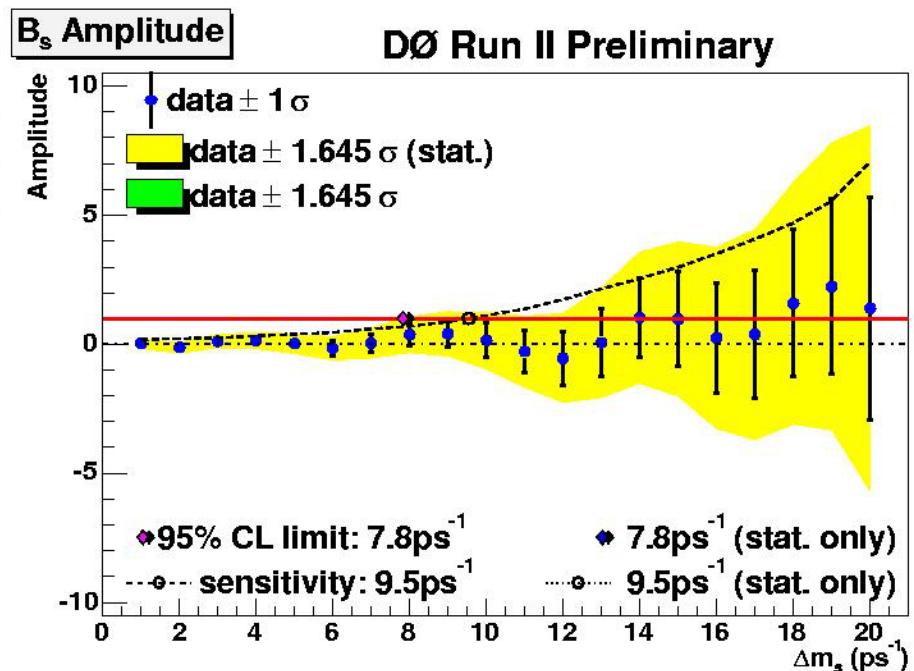
*Summer 2005 Result (610 pb^{-1}):
95% CL limit: 7.0 ps^{-1}
Expected limit: 8.1 ps^{-1}*

Current data set:

95% CL limit: 7.8 ps^{-1}

Expected limit: 9.5 ps^{-1}

Improved Flavor Tagging and increased statistics





Upgrade to Event-by-Event Fit

Minimize $-2 \ln f$

$$f = \prod_{candidates} \left((1 - \mathcal{F}_{sig}) f_{i,bg} + \mathcal{F}_{sig} f_{i,sig} \right)$$

$$f_i = P^{x_M} \left(x_M, \sigma_{x_M}, d_{pr} \right) P^{\sigma_{x_M}} P^{d_{pr}} P^{M_{\phi\pi}} P^{-\log_{10} y}$$

□ Probability Density Functions (PDF) for each source

- Proper Decay Length
- Dilution
- Proper Decay Length Error
- Mass
- Signal Selection Variable



Proper Decay Length

□ Signal

$$P_{sig}^{x^M} = \int_{K_{\min}}^{K_{\max}} D(K) dK \left(\frac{1}{N} \right) Eff(x^M) \int_0^{\infty} dx \cdot G(x - x^M, s\sigma_{x^M}) p^{nos/osc}$$

□ Combinatorial background

➤ Long-lived background

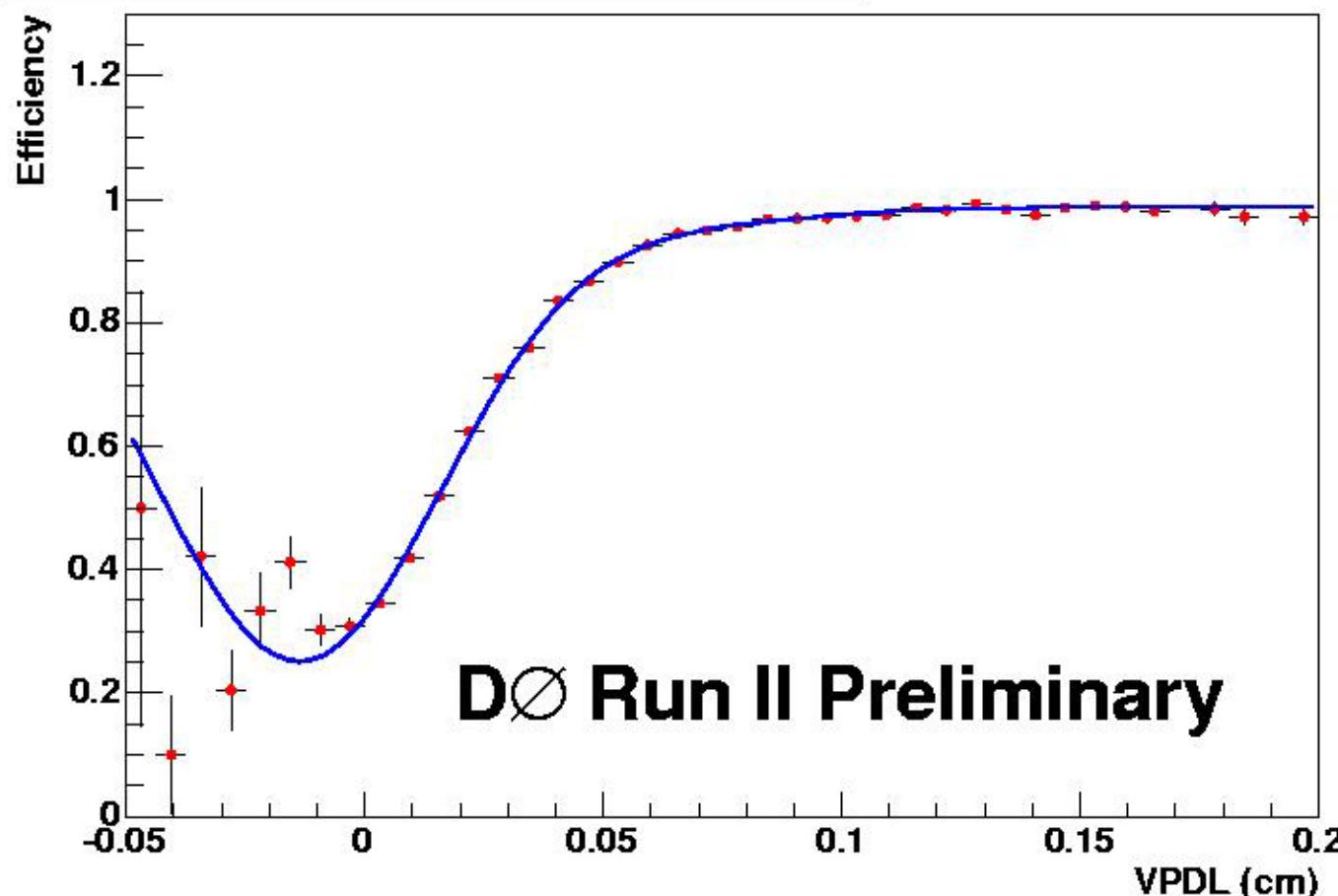
- ✓ Non-sensitive to the tagging
- ✓ Sensitive to the tagging
 - ✓ Non-oscillating
 - ✓ Oscillating with Δm_d frequency

➤ Prompt background

- ✓ Width depends on resolution
- ✓ Constant width

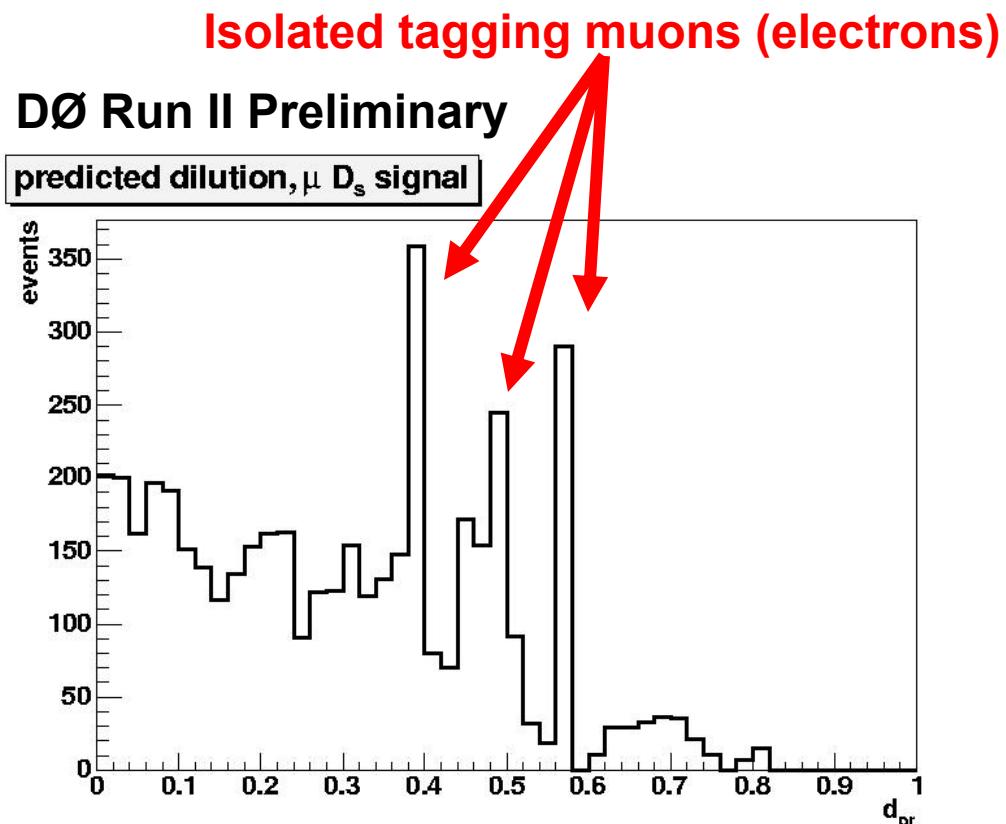
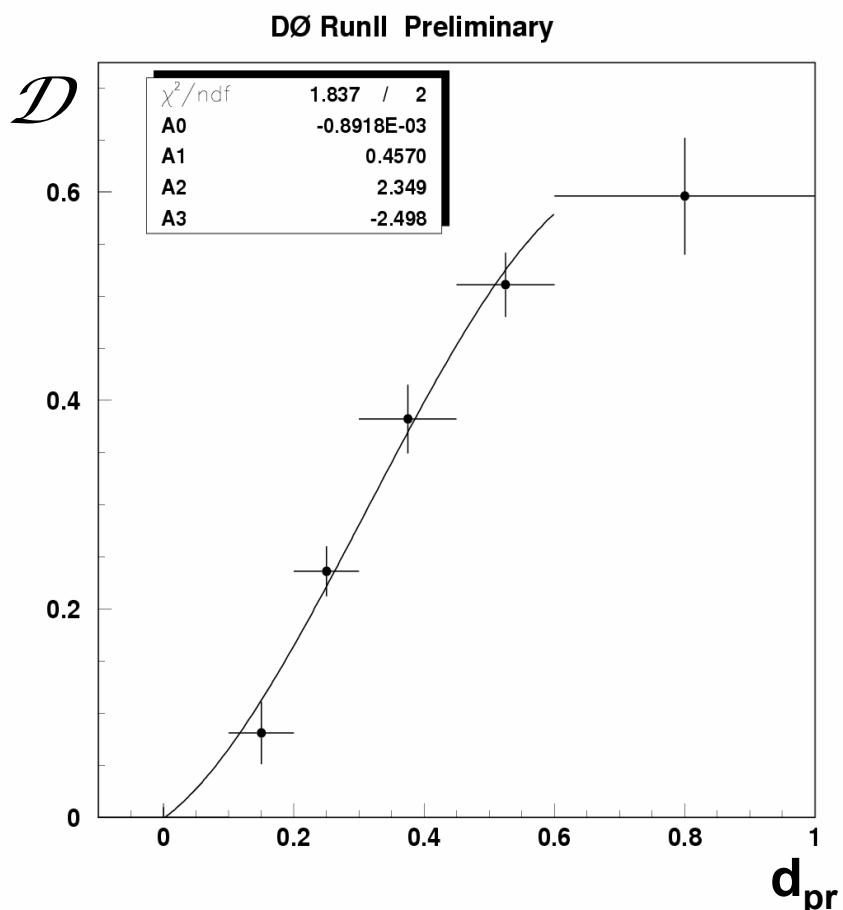
Efficiency Dependence on VPDL

Efficiency vs. VPDL (cm) for $B_s \rightarrow D_s \mu X$



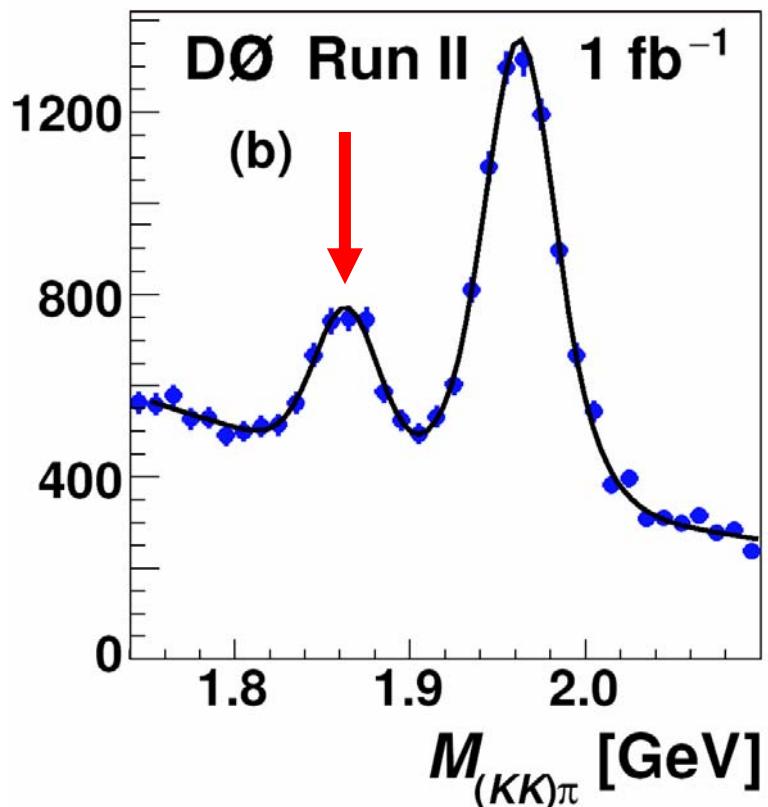
- From MC
 - Cross-checked and tuned using data
- Note that efficiency at VPDL=0 is not 0

Dilution

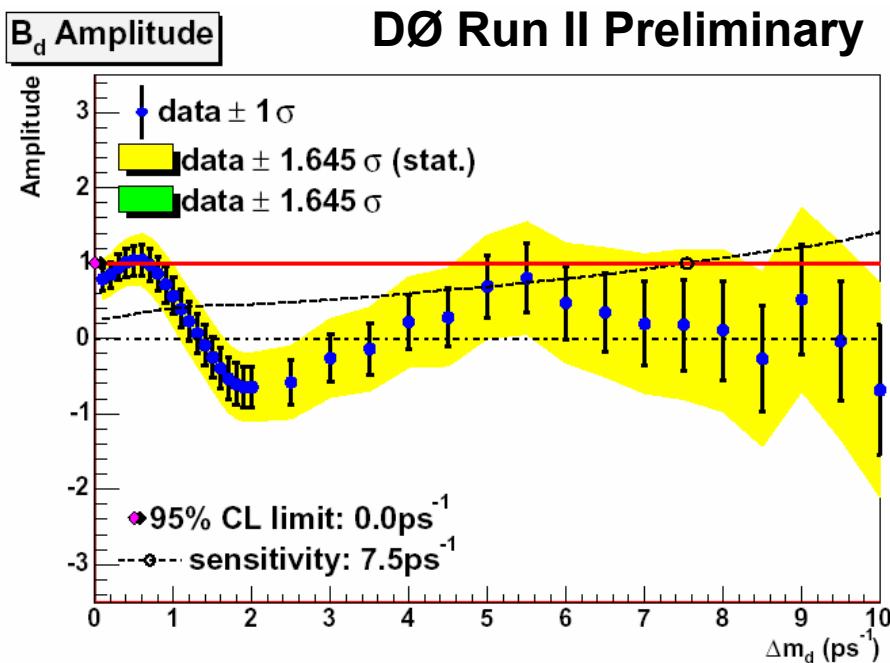


Determine dilution on event-by-event basis

Cross-check Using $B_d \rightarrow X \mu D^\pm (\rightarrow \phi \pi)$



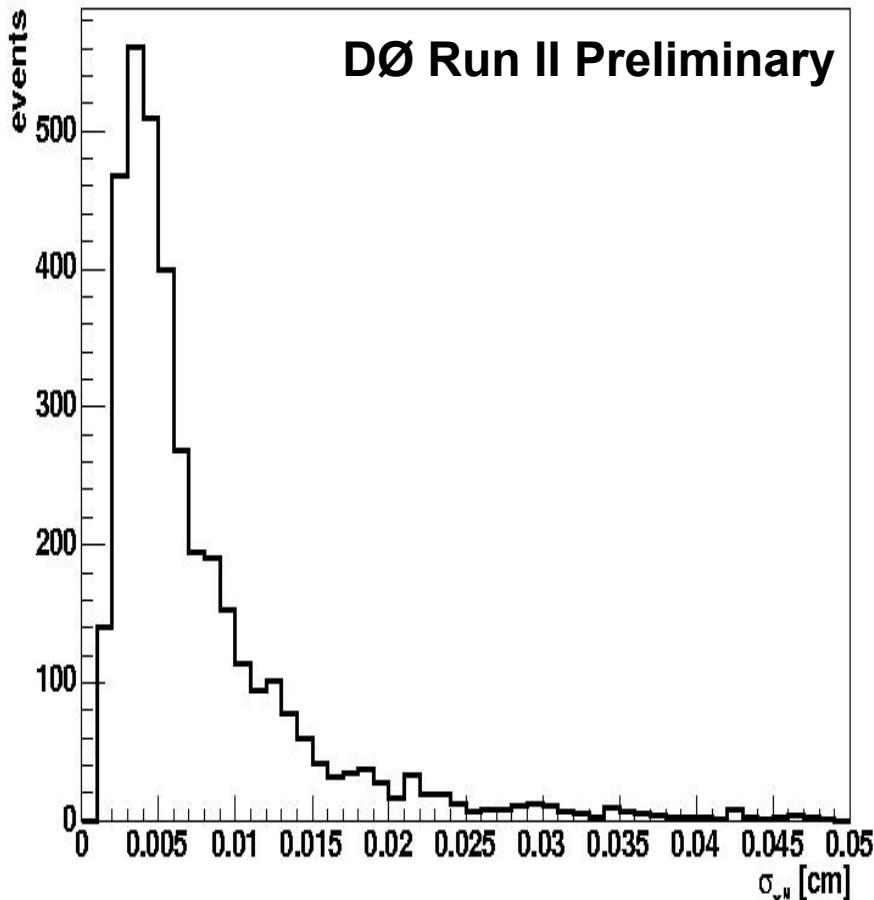
Amplitude Scan



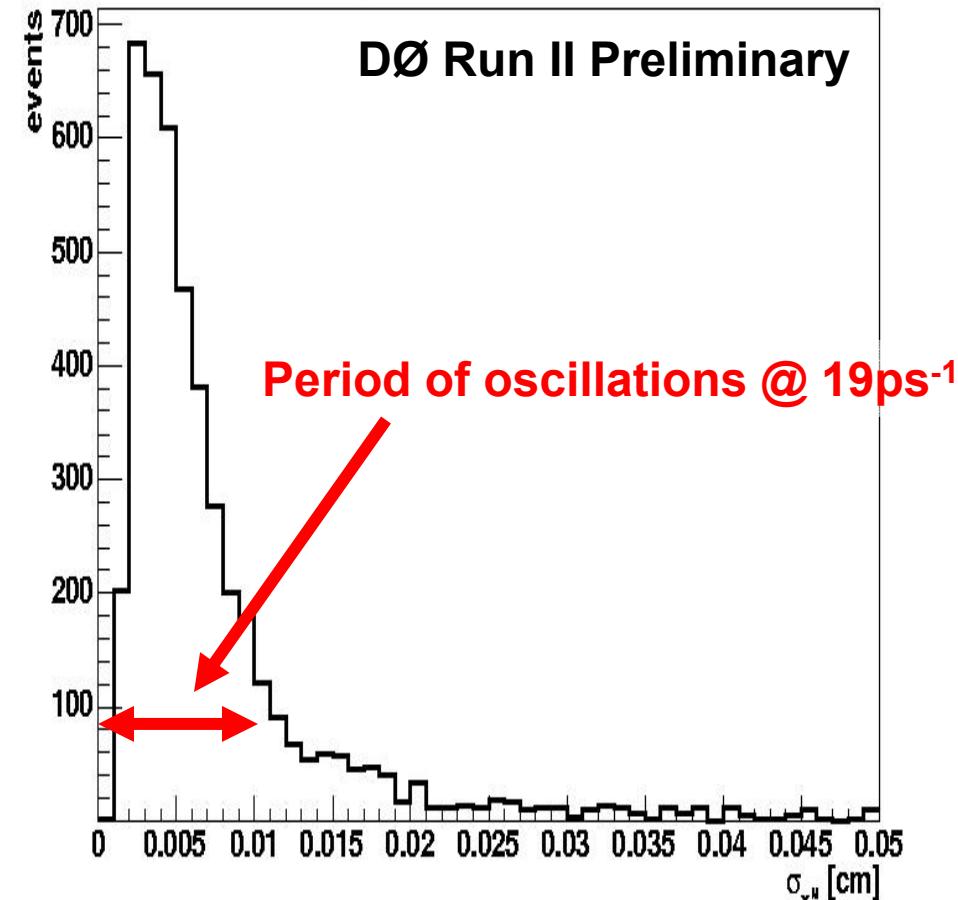
- The Amplitude Scan reveals the B_d oscillations
 - at correct place → no lifetime bias
 - with correct amplitude → correct dilution calibration

Vertex Resolution

VPDL error, background



VPDL error, μD_s signal



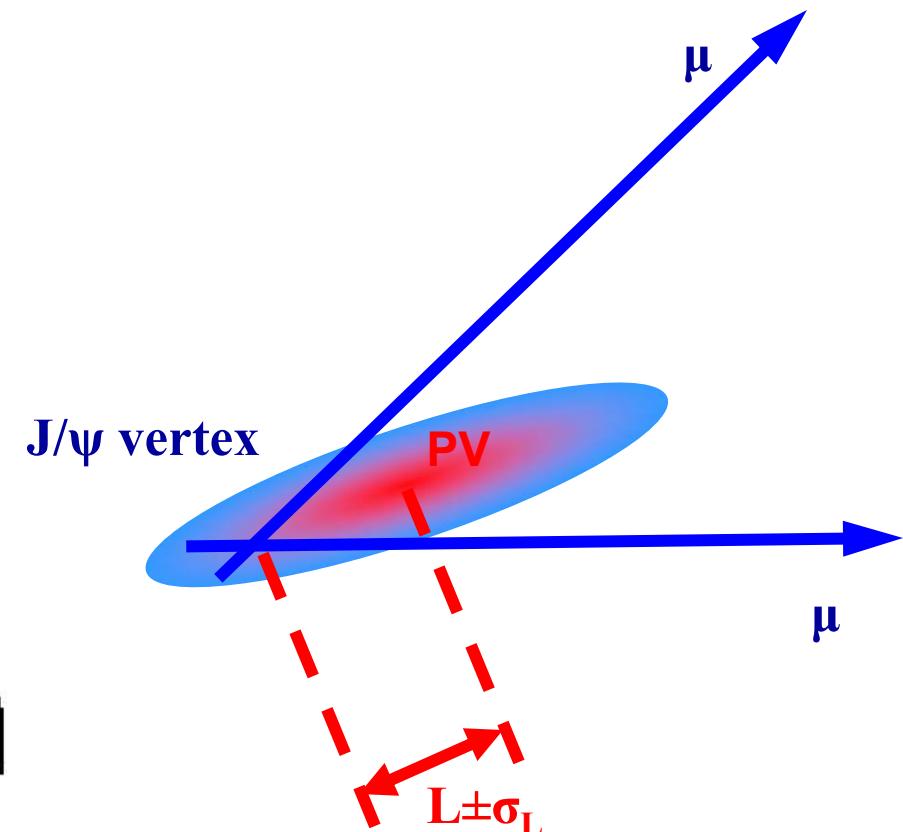
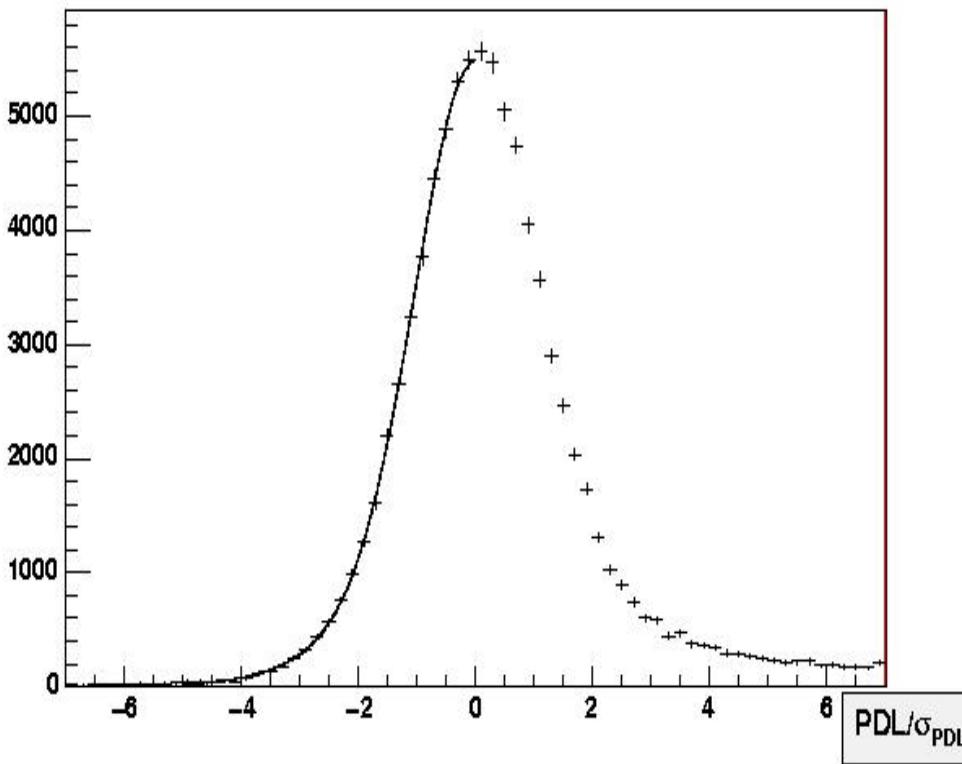
- Determined by vertex fitting procedure

Tuning Resolution Using Data

Use $J/\psi \rightarrow \mu\mu$ sample

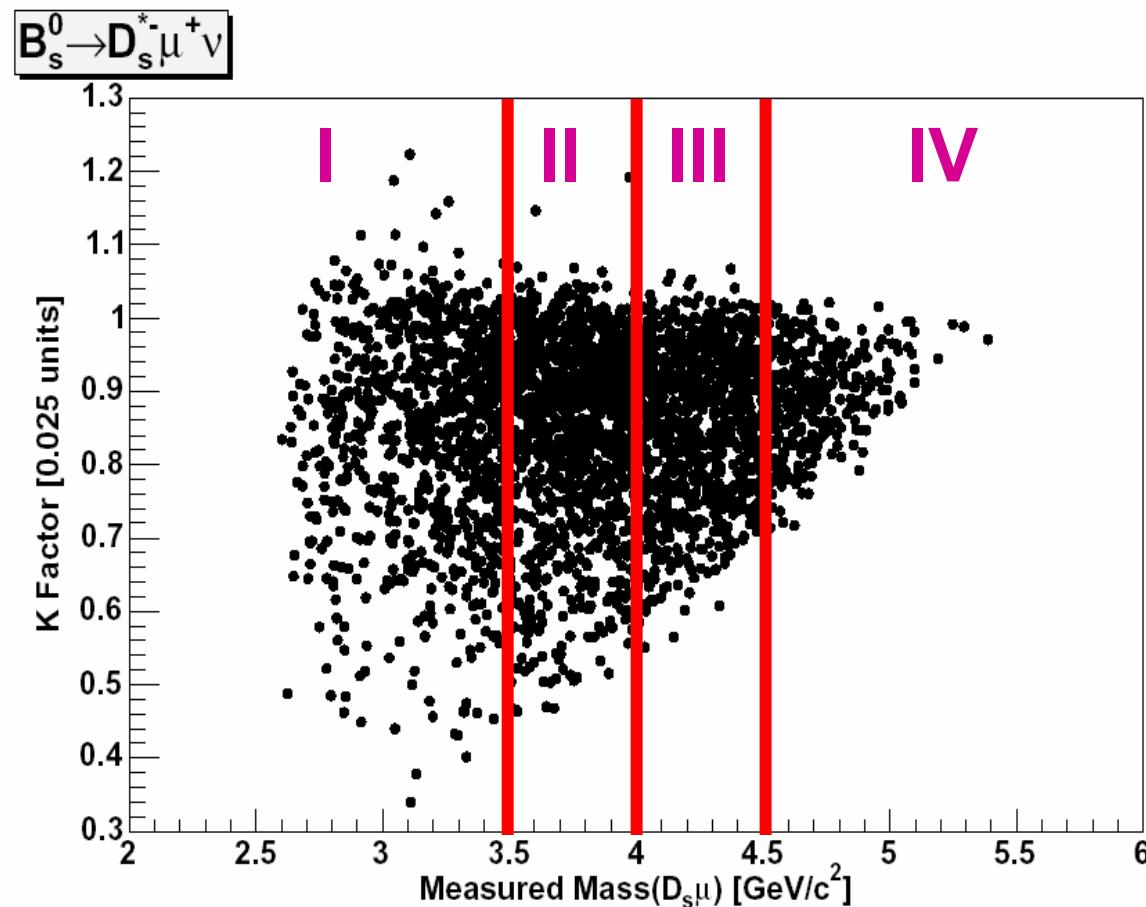
- Fit pull distribution for J/ψ Proper Decay Length with 2 Gaussians
- Resolution Scale Factor is 1.0 for 72% of the events and 1.8 for the rest
- Confirmed by Impact Parameter tuning procedure in MC

DØ Run II Preliminary



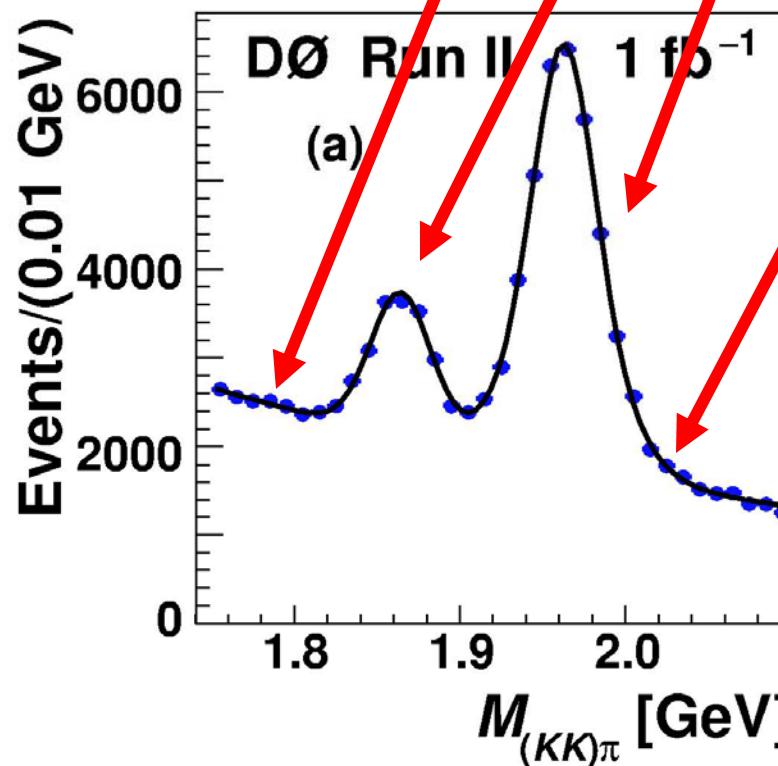
K-factors

- Use different K-factor distributions depending on the mass of μD_s system for D_s and D_s^* samples



$$K = p_T(\mu D_s^-)/p_T(B)$$

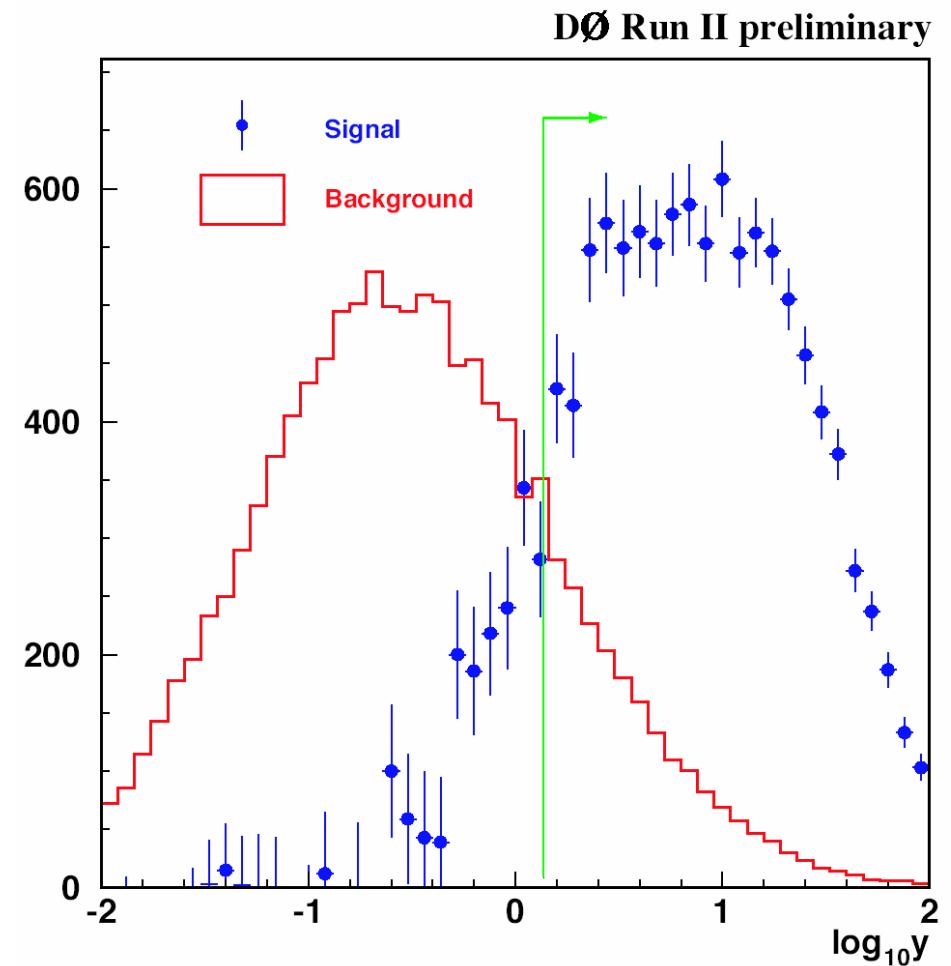
- ❑ Contributions of background, D^+ , D_s and D^+ reflections are taken into account



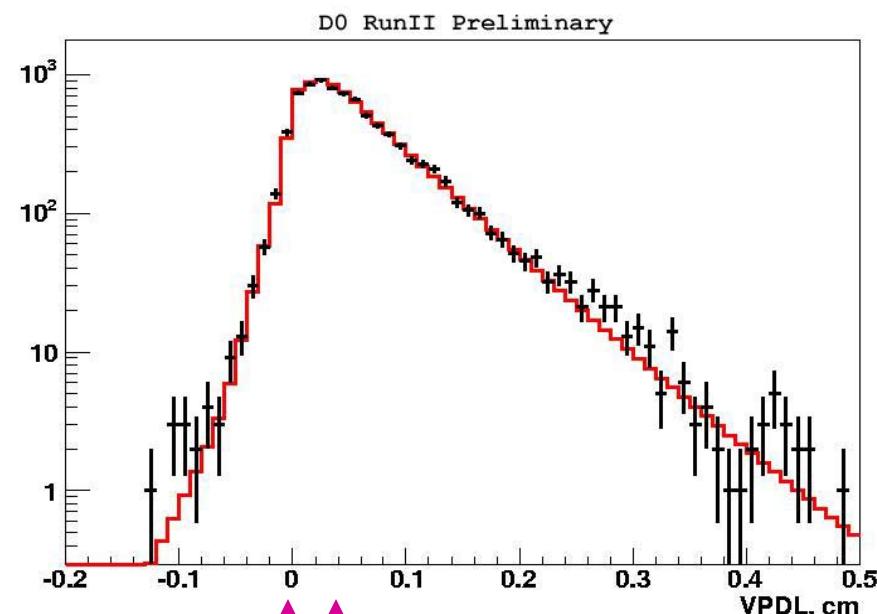
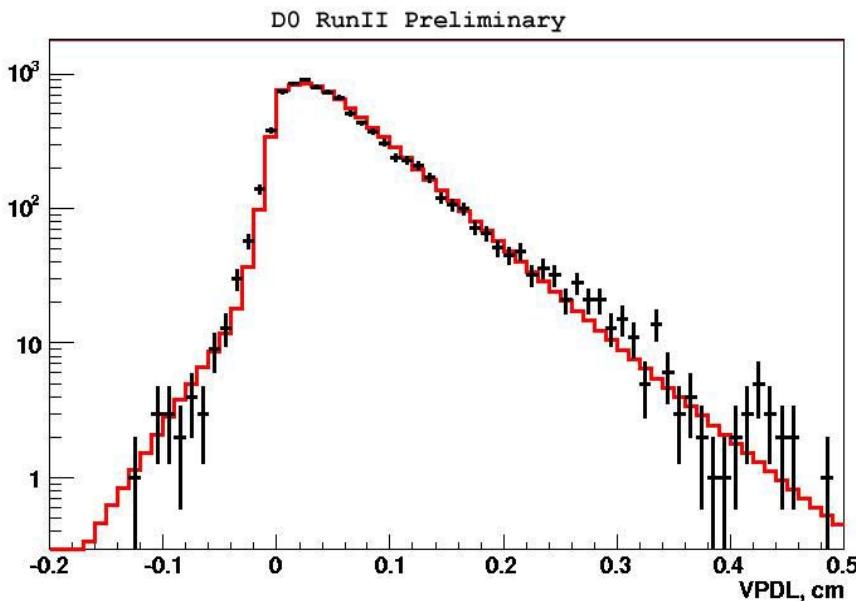
- ❑ Fit in the entire mass region from 1.72 to 2.22 GeV

Signal Selection Function

- Use the signal selection function in the likelihood
 - Use the full information to weight the events



Results of the Lifetime Fit



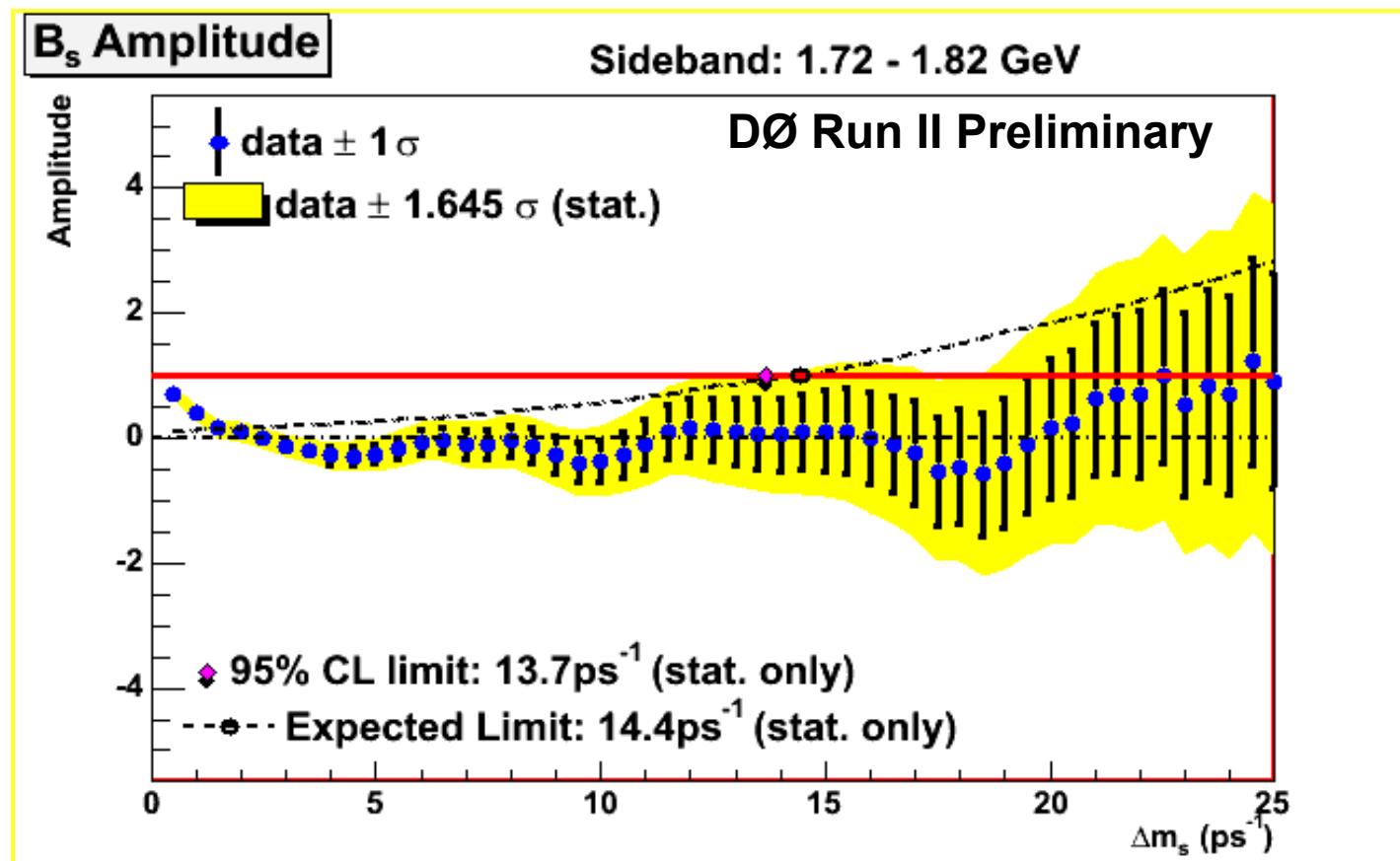
Most important region

- Different background models are used for cross-check and systematic errors
- Trigger biases have been studied
 - Different efficiency models
- Central values for $c\tau_{B_s} = 404 - 416 \mu\text{m}$
 - Statistical error $\sim 10 \mu\text{m}$
 - HFAG value $c\tau_{B_s} = 438 \pm 12 \mu\text{m}$

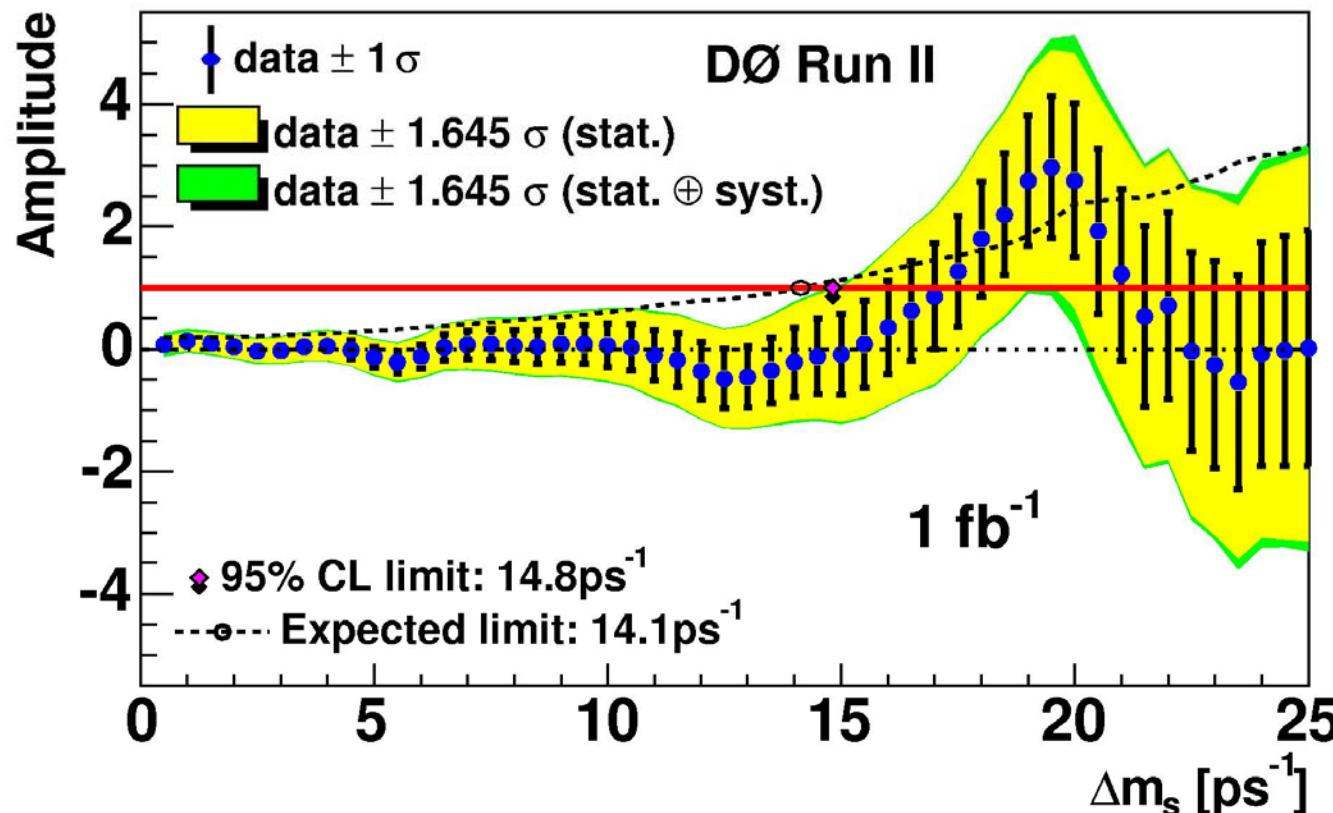


Results for Bs Mixing

Amplitude Scan for Sideband



Amplitude Scan

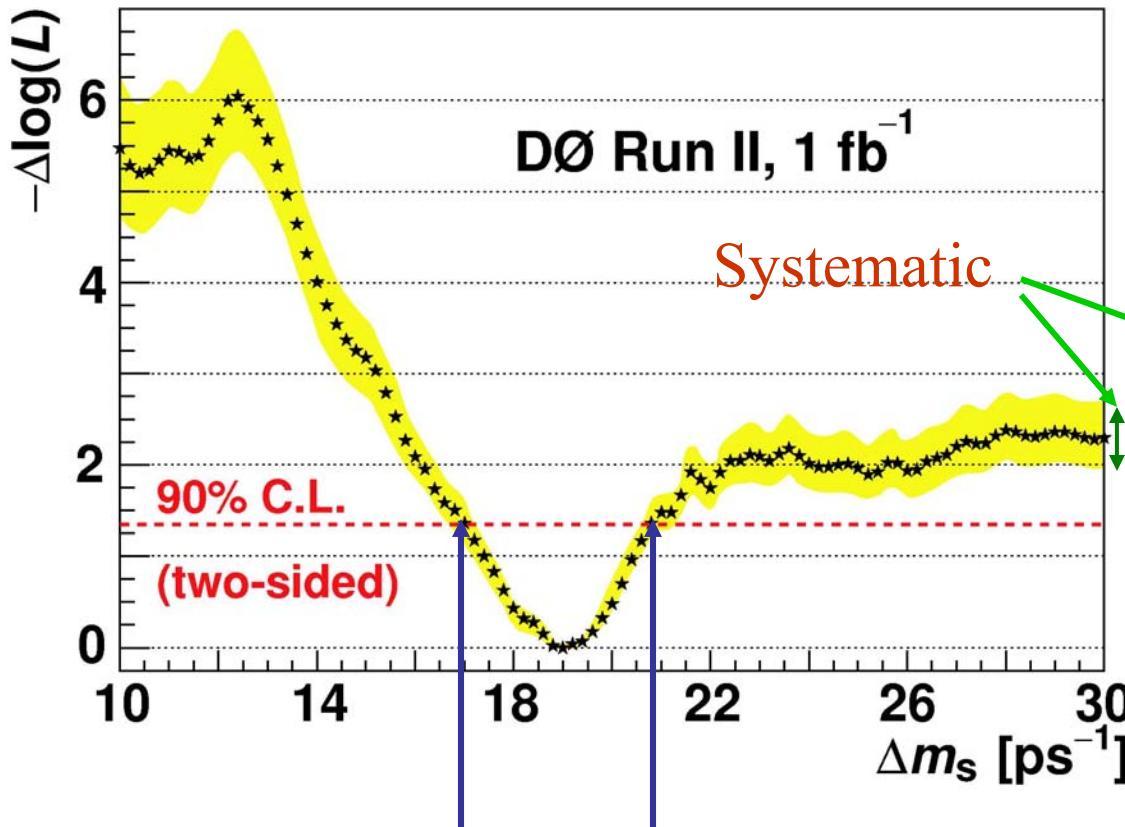


Deviation of the amplitude at $19 ps^{-1}$

- 2.5σ from 0
- 1.6σ from 1

Log Likelihood Scan

In agreement with the amplitude scan



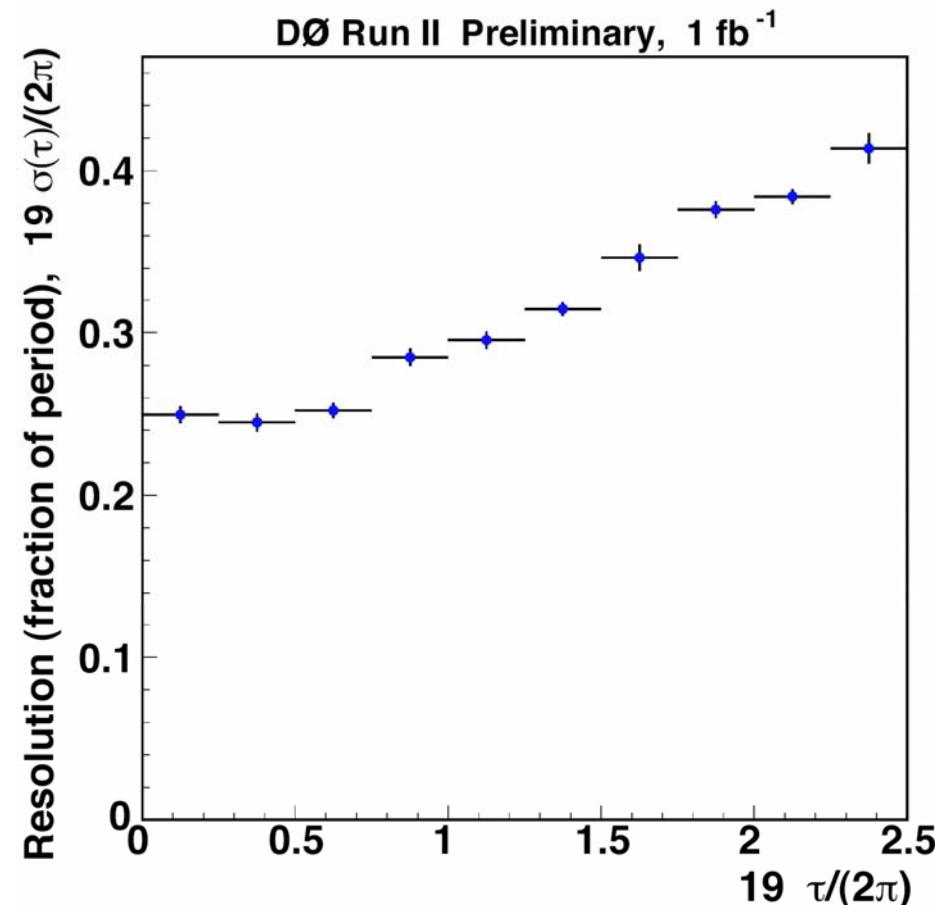
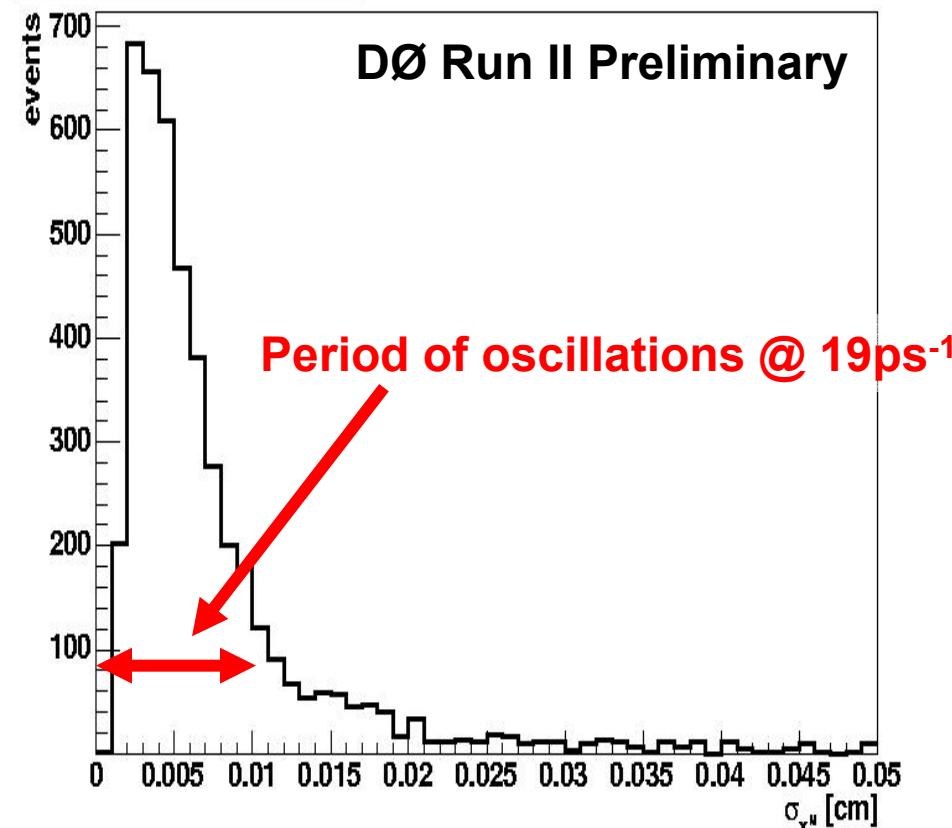
- Resolution
- K-factor variation
- BR ($B_s \rightarrow \mu D_s X$)
- VPDL model
- BR ($B_s \rightarrow D_s D_s$)

Have no sensitivity
above 22 ps^{-1}

$17 < \Delta m_s < 21 \text{ ps}^{-1}$ @ 90% CL assuming Gaussian errors
Most probable value of $\Delta m_s = 19 \text{ ps}^{-1}$

“Golden” Events for Visualization

VPDL error, μD_s signal

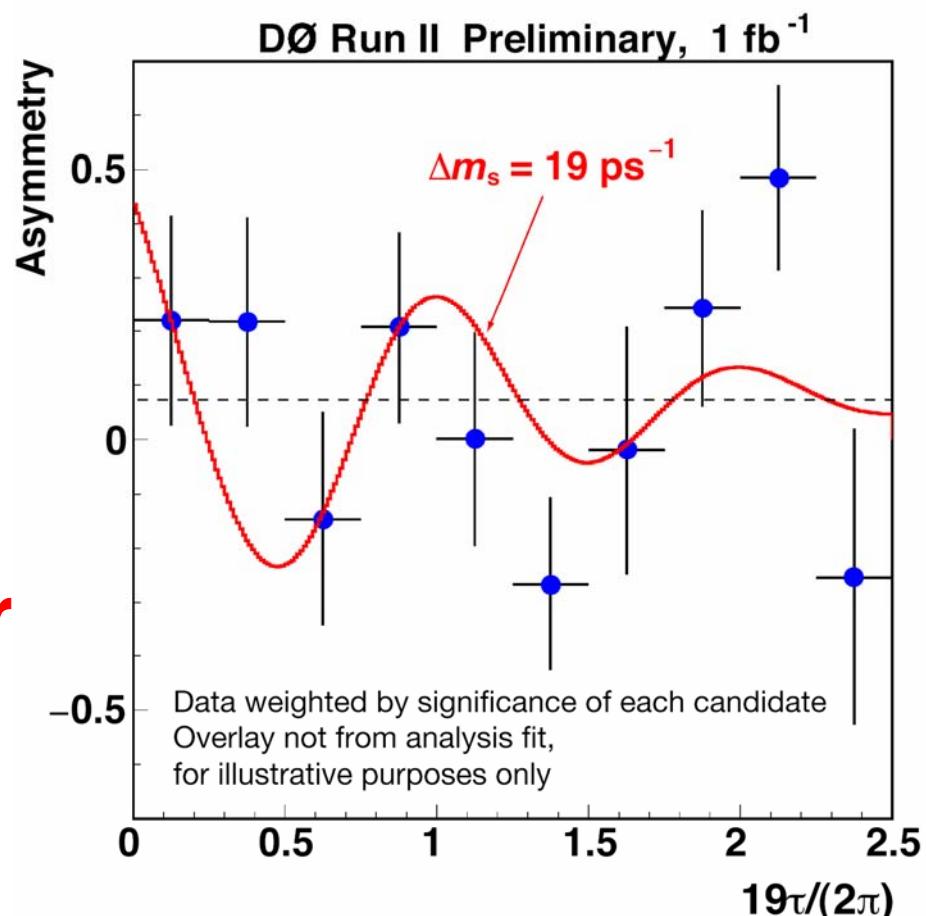


Weight events using

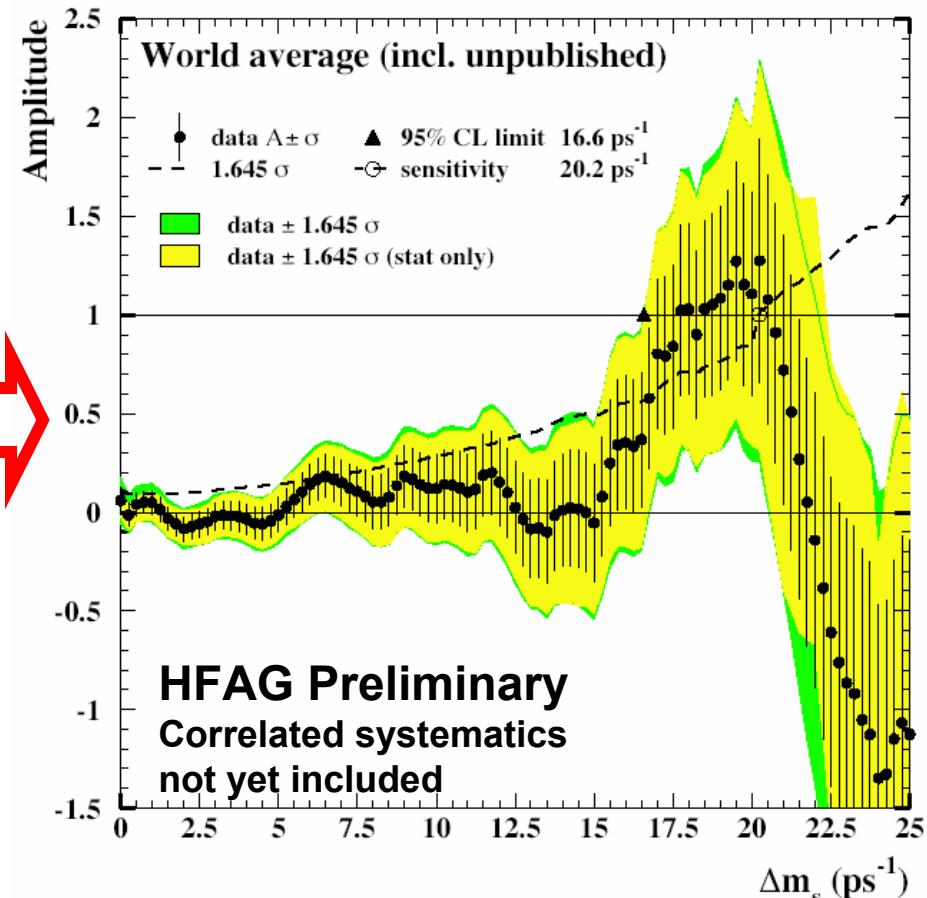
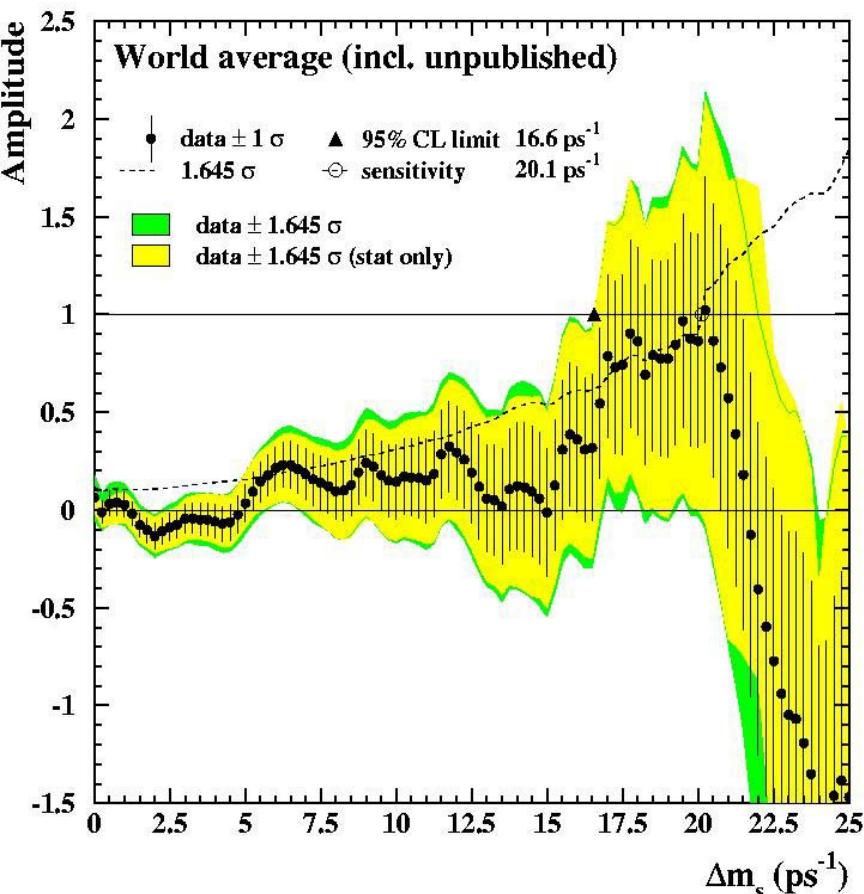
$$Signif = \mathcal{F}_{sig}(M_{\phi\pi}, \log_{10} y) \cdot |\mathcal{D}| \cdot e^{-\frac{(\Delta m_s \sigma_\tau)^2}{2}}$$

See Bs Oscillations By Eye!

- Weighted asymmetry
- This plot does not represent the full statistical power of our data



World Average

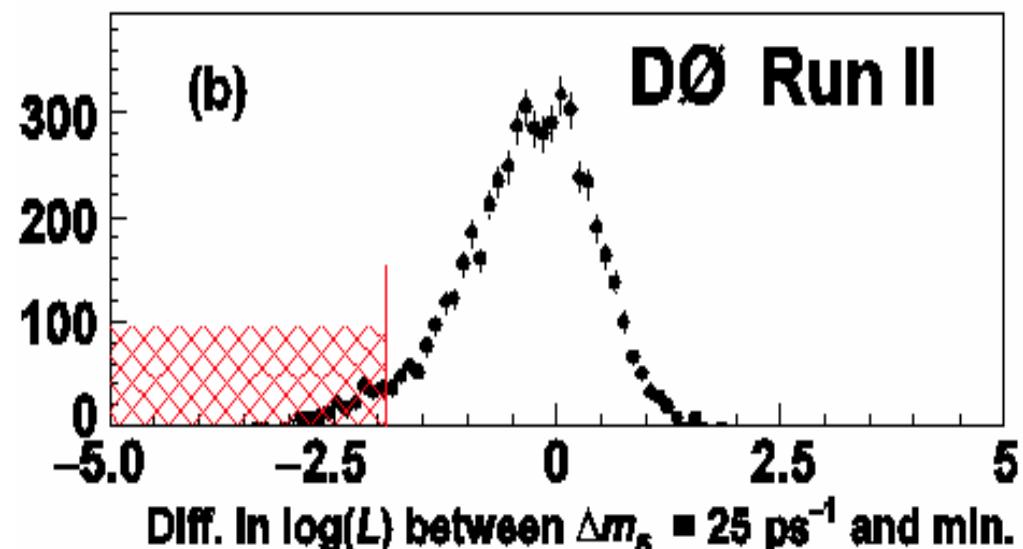


@ 19 ps^{-1} : $1.5\sigma \rightarrow 2.3\sigma$

Ensemble Tests

□ Using data

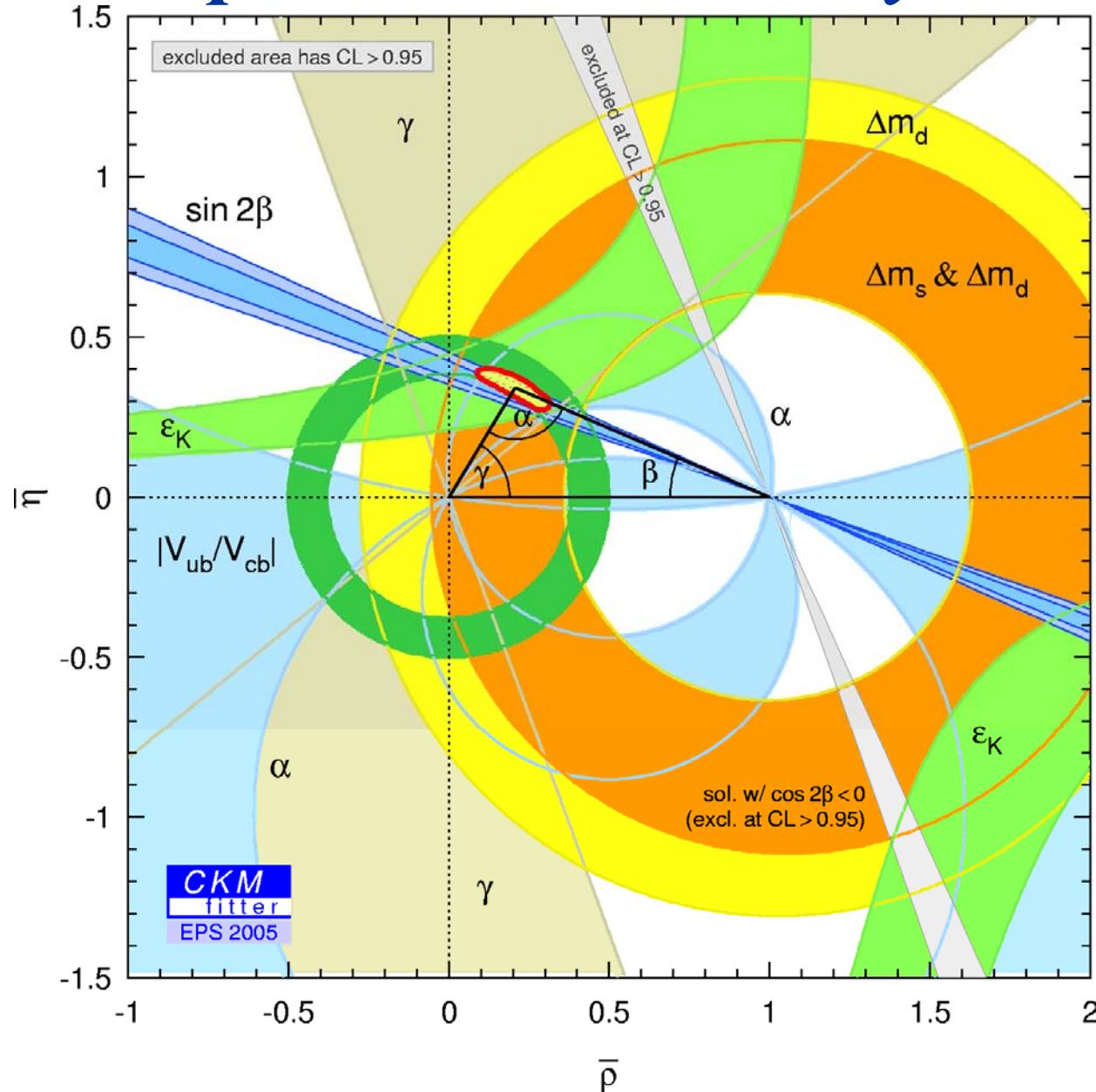
- Simulate $\Delta m_s = \infty$ by randomizing the sign of flavor tagging
- Probability to observe $\Delta \log(L) > 1.9$ (as deep as ours) in the range $16 < \Delta m_s < 22 \text{ ps}^{-1}$ is 3.8%
 - ✓ 5% using lower edge of syst. uncertainties band
 - ✓ Region below 16 ps^{-1} is experimentally excluded
 - ✓ No sensitivity above 22 ps^{-1}



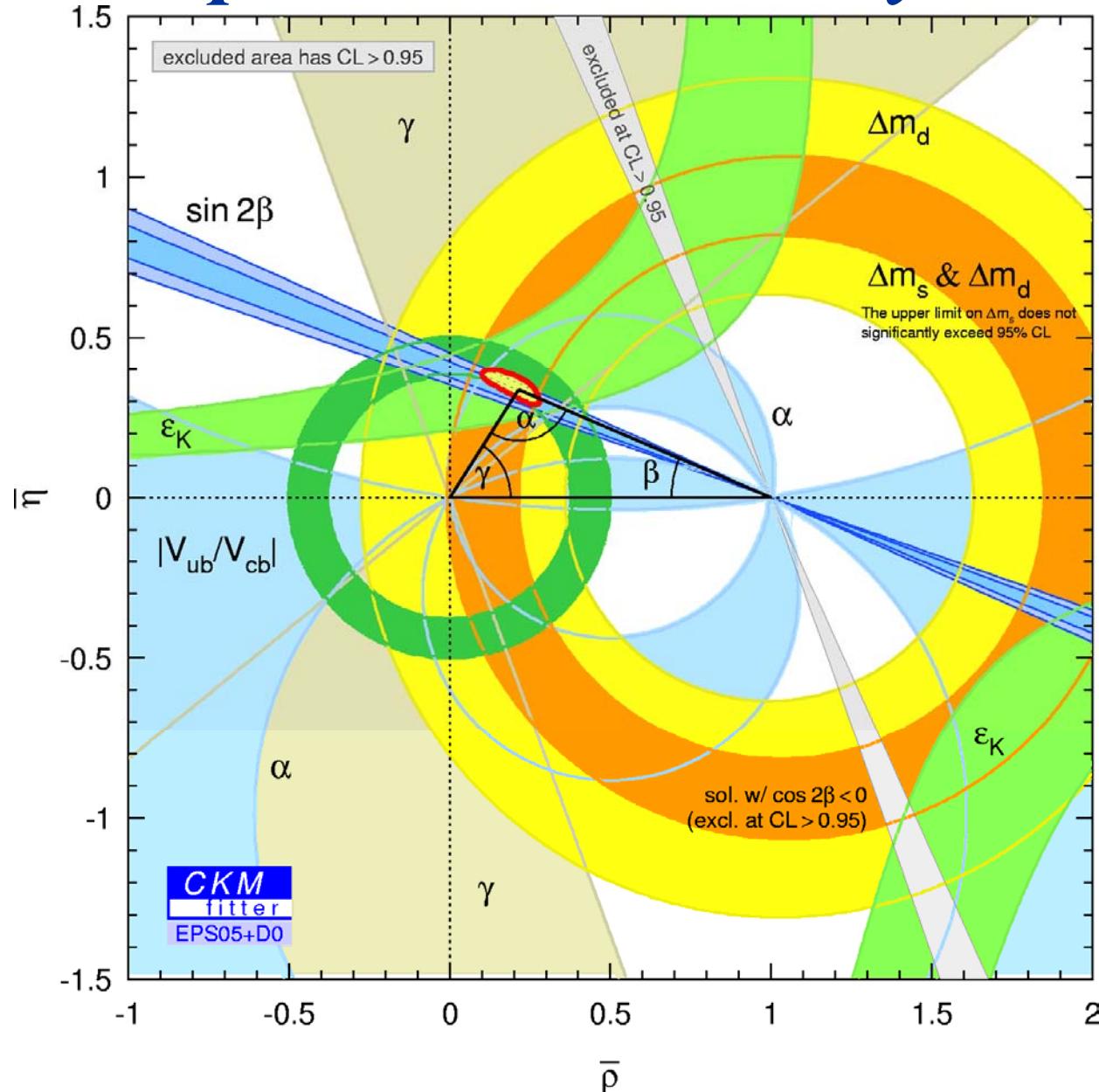
□ Using MC

- Probability to observe $\Delta \log(L) > 1.9$ for the true $\Delta m_s = 19 \text{ ps}^{-1}$ in the range $17 < \Delta m_s < 21 \text{ ps}^{-1}$ is 15%

Impact on the Unitarity Triangle



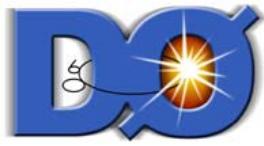
Impact on the Unitarity Triangle





Conclusion

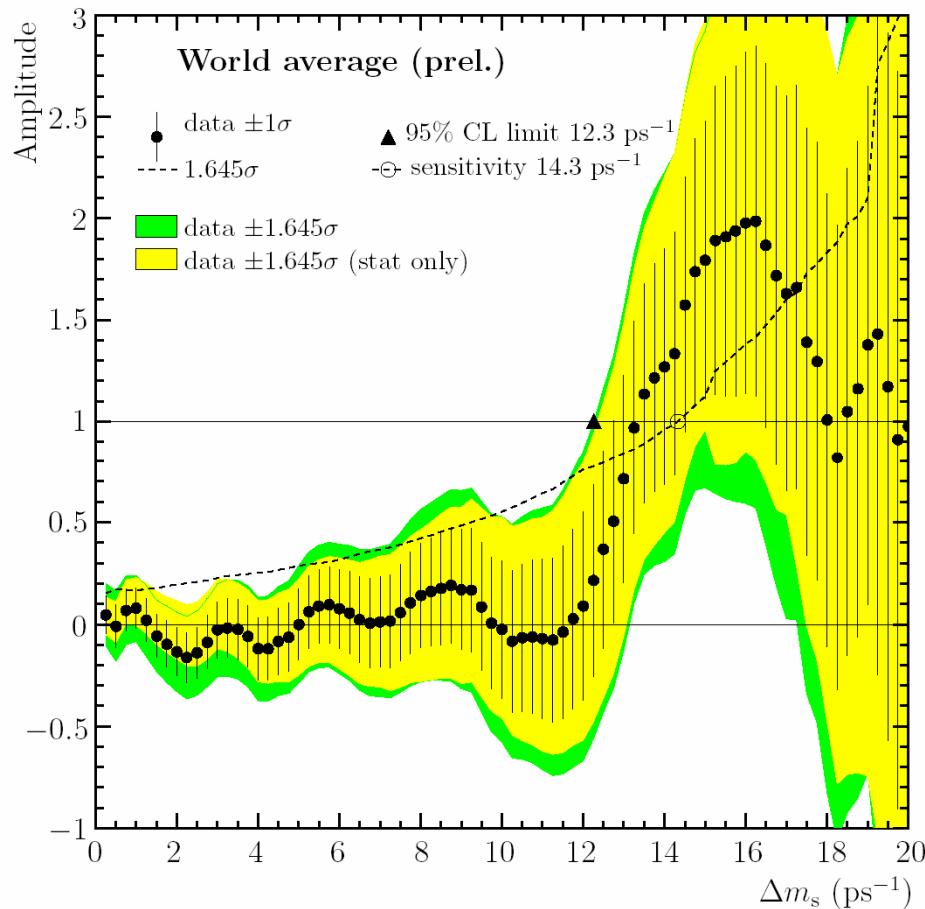
- ❑ 1 fb⁻¹ Data sample was used for the Bs oscillation measurement
- ❑ 2.5 σ deviation from 0 is observed in the amplitude scan at 19 ps⁻¹
 - in agreement with the loglikelihood scan
 - 90% C.L. interval for Δm_s : 17 – 21 ps⁻¹ assuming Gaussian errors
- ❑ Improvements for the summer
 - New decay modes in the semileptonic analyses
 - ✓ $D_s \rightarrow K^* K$, $K_S K$, 3π
 - ✓ $e^+ D_s$
 - Hadronic Modes
 - Same-Side Tagging
- ❑ Layer 0 is being installed
- ❑ Stay Tuned



Backup Slides

Analysis of the Combination of Experimental Results by Abbaneo & Boix (1999)

JHEP08 (1999) 004



- Probability of statistical fluctuation: $1 - \text{C.L.} \approx 3\%$
- $\Delta m_s = 14.8^{+2.7}_{-1.8} \text{ ps}^{-1} \rightarrow \text{interval } 13.0 - 17.5 \text{ ps}^{-1}$

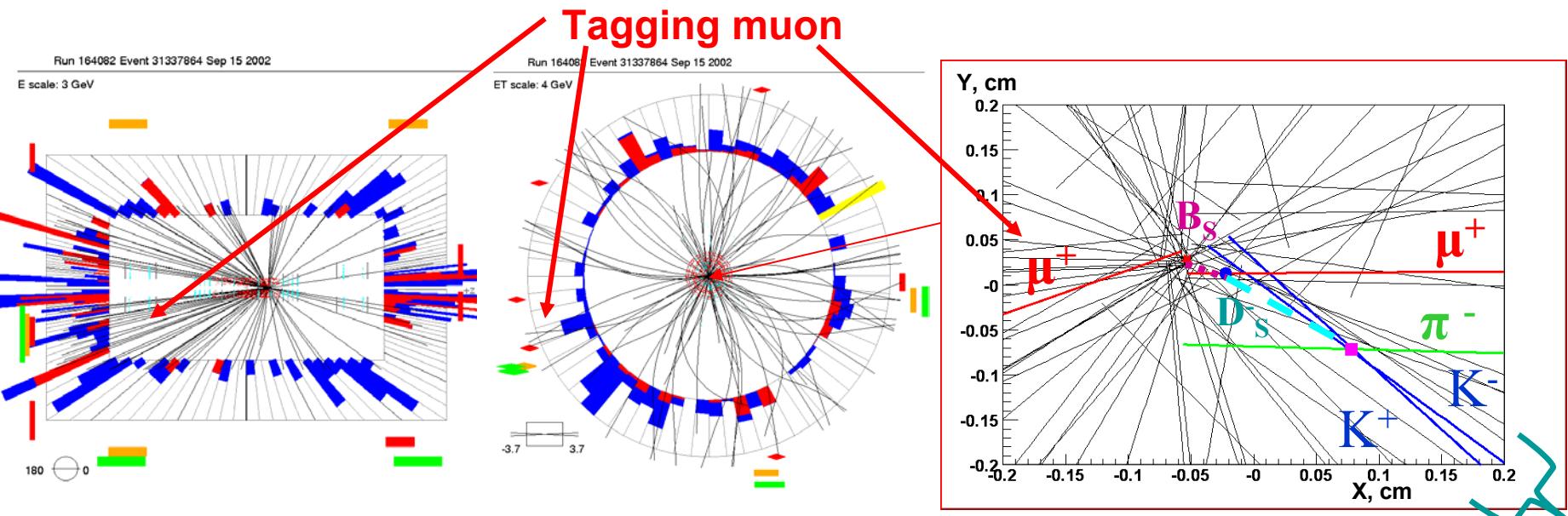


Systematic Uncertainties

Osc. frequency		1 ps ⁻¹	3 ps ⁻¹	5 ps ⁻¹	7 ps ⁻¹	9 ps ⁻¹	11 ps ⁻¹	13 ps ⁻¹	15 ps ⁻¹	17 ps ⁻¹	19 ps ⁻¹	21 ps ⁻¹	23 ps ⁻¹	25 ps ⁻¹
\mathcal{A}		0.128	-0.025	-0.134	0.073	0.079	-0.100	-0.459	-0.093	0.858	2.749	1.218	-0.253	0.018
Stat. uncertainty		0.090	0.124	0.167	0.231	0.299	0.410	0.504	0.659	0.864	1.068	1.413	1.690	1.920
Br($D_s\bar{D}_s$) = 4.7%	$\Delta\mathcal{A}$	-0.003	+0.000	+0.003	-0.002	-0.002	+0.003	+0.010	+0.001	-0.022	-0.059	-0.021	+0.012	+0.009
	$\Delta\sigma$	-0.002	-0.003	-0.004	-0.005	-0.006	-0.009	-0.010	-0.014	-0.018	-0.023	-0.029	-0.035	-0.040
Br($D_s\mu\bar{X}$) = 6.7%	$\Delta\mathcal{A}$	+0.006	-0.003	-0.005	-0.004	-0.001	-0.003	-0.011	-0.004	+0.012	+0.046	+0.023	-0.001	+0.011
	$\Delta\sigma$	+0.002	+0.002	+0.003	+0.004	+0.005	+0.007	+0.009	+0.011	+0.015	+0.019	+0.024	+0.030	+0.035
$p_{T\mu} > 6 \text{ GeV}/c$	$\Delta\mathcal{A}$	-0.015	+0.009	+0.013	+0.010	-0.001	+0.010	+0.029	+0.013	-0.045	-0.124	-0.044	-0.023	-0.019
	$\Delta\sigma$	-0.004	-0.006	-0.008	-0.011	-0.014	-0.019	-0.024	-0.031	-0.042	-0.054	-0.066	-0.081	-0.093
K-factor variation 2%	$\Delta\mathcal{A}$	-0.000	+0.006	-0.024	+0.001	+0.010	-0.041	+0.045	+0.104	+0.231	+0.207	-0.380	+0.006	-0.001
	$\Delta\sigma$	+0.000	+0.001	+0.002	+0.004	+0.007	+0.012	+0.011	+0.027	+0.025	+0.059	+0.040	+0.049	+0.050
K-factor distribution smoothed	$\Delta\mathcal{A}$	+0.000	-0.000	-0.001	+0.001	-0.002	+0.013	+0.006	+0.036	+0.028	-0.003	+0.171	+0.033	+0.032
	$\Delta\sigma$	+0.000	+0.000	+0.000	+0.000	+0.001	+0.001	+0.002	+0.003	+0.003	+0.005	+0.004	+0.008	+0.009
K-factor from measured momenta	$\Delta\mathcal{A}$	-0.000	-0.001	+0.003	+0.001	-0.009	+0.026	+0.003	+0.055	+0.048	-0.021	+0.248	+0.003	-0.050
	$\Delta\sigma$	+0.000	+0.000	+0.000	+0.001	+0.001	+0.002	+0.003	+0.005	+0.004	+0.006	+0.006	+0.005	+0.011
Fraction of peaking bkg. (combinatorial bkg.)	$\Delta\mathcal{A}$	+0.002	+0.001	-0.000	-0.001	-0.000	+0.000	-0.000	+0.001	+0.004	+0.012	+0.007	+0.002	+0.008
	$\Delta\sigma$	+0.000	-0.000	-0.000	+0.000	+0.000	+0.000	+0.001	+0.001	+0.001	+0.001	+0.003	+0.004	+0.004
Fraction of peaking bkg. (signal)	$\Delta\mathcal{A}$	+0.001	-0.000	-0.002	-0.000	-0.002	-0.007	-0.016	-0.013	+0.004	+0.055	+0.014	-0.035	-0.021
	$\Delta\sigma$	+0.001	+0.001	+0.001	+0.002	+0.002	+0.004	+0.005	+0.007	+0.012	+0.014	+0.026	+0.034	+0.039
$c\tau\text{-}B\text{-}s$	$\Delta\mathcal{A}$	+0.001	+0.001	+0.002	-0.000	-0.001	+0.003	+0.003	-0.001	-0.010	-0.029	+0.003	+0.013	+0.000
	$\Delta\sigma$	-0.000	-0.000	-0.001	-0.001	-0.002	-0.002	-0.003	-0.004	-0.006	-0.007	-0.011	-0.014	-0.015
uncertainty in reflection	$\Delta\mathcal{A}$	-0.002	+0.001	-0.001	+0.001	+0.002	+0.002	-0.001	-0.003	+0.000	+0.008	+0.008	+0.002	-0.001
	$\Delta\sigma$	+0.000	+0.000	+0.000	+0.001	+0.001	+0.001	+0.001	+0.001	+0.002	+0.002	+0.003	+0.004	+0.004
Stat. fluctuation of $N\text{-}D\text{-}s$	$\Delta\mathcal{A}$	-0.001	+0.000	+0.000	+0.001	-0.000	-0.001	-0.000	+0.003	+0.008	+0.016	+0.011	+0.004	+0.009
	$\Delta\sigma$	+0.000	+0.001	+0.001	+0.001	+0.001	+0.002	+0.002	+0.003	+0.004	+0.004	+0.008	+0.009	+0.009
resolution (signal)	$\Delta\mathcal{A}$	+0.001	+0.002	+0.004	+0.010	+0.007	-0.000	-0.019	-0.012	+0.019	+0.075	+0.040	+0.025	+0.076
	$\Delta\sigma$	+0.000	+0.001	+0.002	+0.004	+0.007	+0.012	+0.016	+0.023	+0.035	+0.046	+0.068	+0.087	+0.102
resolution (bkg.)	$\Delta\mathcal{A}$	+0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.003	-0.006	-0.009	-0.009	-0.011
	$\Delta\sigma$	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.001	-0.001
dilution	$\Delta\mathcal{A}$	-0.005	-0.002	+0.008	+0.021	-0.010	-0.006	+0.001	+0.002	-0.015	-0.042	+0.037	+0.112	+0.129
	$\Delta\sigma$	-0.001	-0.001	-0.001	-0.002	-0.003	-0.005	-0.004	-0.005	-0.004	-0.002	-0.017	-0.018	-0.018
$Fr\text{-}tsens$	$\Delta\mathcal{A}$	-0.010	+0.006	+0.003	+0.003	+0.003	+0.000	-0.002	-0.004	-0.005	-0.004	-0.000	+0.001	-0.005
	$\Delta\sigma$	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	+0.000	+0.000	-0.000
$Fr\text{-osc}$	$\Delta\mathcal{A}$	-0.005	-0.000	+0.000	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.003	-0.004	-0.006	-0.006
	$\Delta\sigma$	+0.000	+0.000	+0.000	+0.000	0.000	+0.000	-0.000	-0.000	+0.000	+0.000	0.000	-0.000	0.000
Fit to VPDL distribution	$\Delta\mathcal{A}$	+0.008	+0.010	+0.014	+0.030	+0.041	+0.044	+0.004	+0.026	+0.129	+0.379	+0.291	+0.149	+0.363
	$\Delta\sigma$	+0.002	+0.001	+0.001	+0.003	+0.006	+0.013	+0.021	+0.034	+0.045	+0.043	+0.100	+0.147	+0.179
Non-zero $\Delta\Gamma$	$\Delta\mathcal{A}$	+0.000	+0.000	+0.001	+0.000	+0.000	+0.001	+0.001	+0.000	-0.001	-0.005	-0.003	+0.001	-0.001
	$\Delta\sigma$	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.000	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002
Total syst.	σ_{tot}^{sys}	0.071	0.057	0.056	0.068	0.090	0.106	0.117	0.194	0.286	0.337	0.565	0.309	0.497
Total	σ_{tot}	0.115	0.137	0.176	0.241	0.313	0.423	0.517	0.687	0.910	1.119	1.522	1.718	1.983

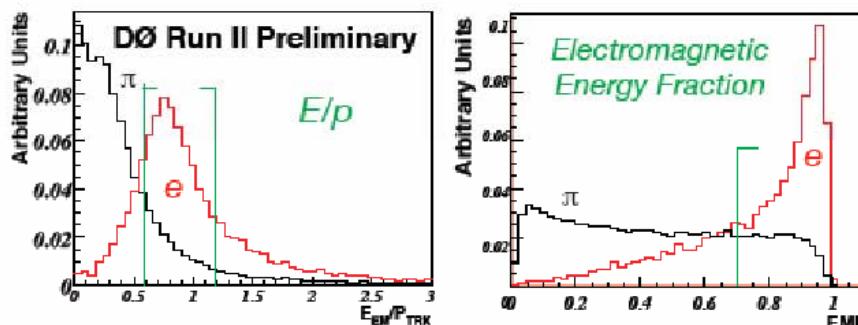
Oscillated B_s candidate in Run 164082 Event 31337864

- Two same sign muons are detected
 - Tagging muon has $\eta=1.4$
 - See advantage of muon system with large coverage
- $M_{KK}=1.019 \text{ GeV}$, $M_{KK\pi}=1.94 \text{ GeV}$
- $P_T(\mu_{B_s})=3.4 \text{ GeV}$; $P_T(\mu_{tag})=3.5 \text{ GeV}$



Flavor Tagging

- ❖ Semileptonic b decay - Lepton tag (Muon and Electron). Charge of the lepton tags the flavor of b.
 - First use of low pt electrons in a heavy-flavor analysis. ($P_T > 2 \text{ GeV}$, $|\eta| < 1.1$)



- ❖ Secondary Vertex Charge $Q_{SV} = \frac{\sum_i (q^i p_L^i)^k}{\sum_i (p_L^i)^k}$
 $\cos\phi(p_{SV}, p_B) < 0.8$

Sum over tracks assoc. to secondary vertex.

- ❖ Event charge $Q_{EV} = \frac{\sum_i q^i p_T^i}{\sum_i p_T^i}$
 $\cos\phi(p, p_B) < 0.8$

*Combine variables
into a single
tagging variable*

Flavor tagging (Combined tag algorithm)

- Get tag on opposite side and construct PDF's for variables discriminating b (μ^-) and \bar{b} (μ^+) (Use $B^+ \rightarrow D^0 (X)$ decays in data)

$$y = \prod_{i=1}^n y_i; \quad y_i = \frac{f_i^b(x_i)}{f_i^{\bar{b}}(x_i)}$$

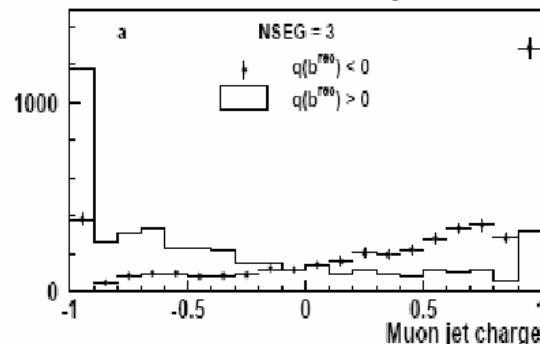
$$d = \frac{1-y}{1+y}$$

- Discriminating variables (x^i):

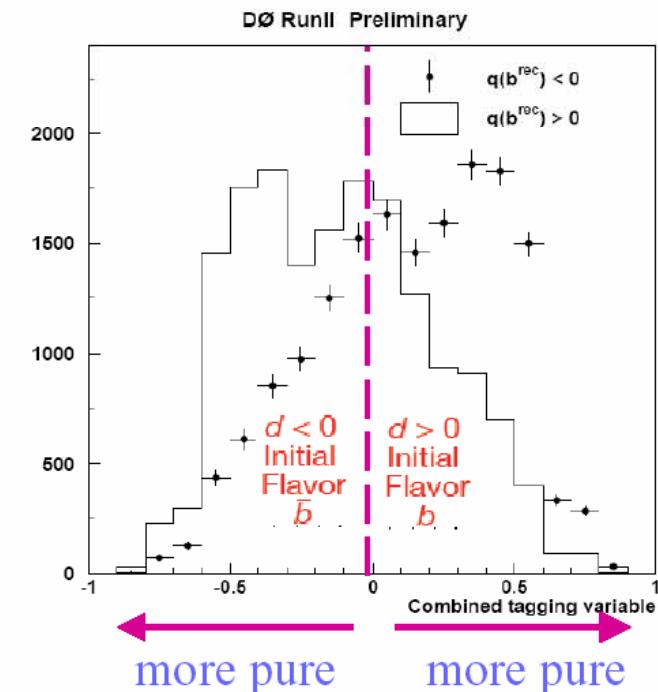
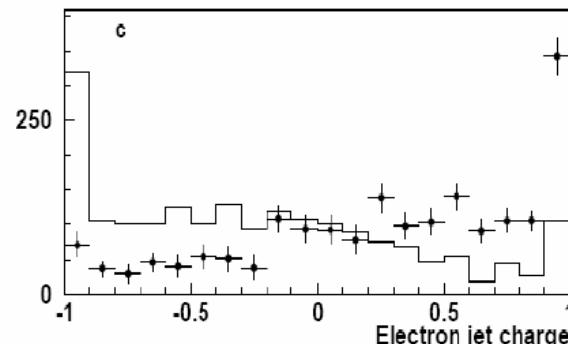
$$Q_J^\mu = \frac{\sum_i q^i p_T^i}{\sum_i p_T^i} \quad Q_{SV} = \frac{\sum_i (q^i p_L^i)^k}{\sum_i (p_L^i)^k} \quad Q_{EV} = \frac{\sum_i q^i p_T^i}{\sum_i p_T^i}$$

Electron/Muon *SV Tagger*

DØ RunII Preliminary



DØ RunII Preliminary





Performance of Different Taggers

Tagger	$\varepsilon(\%)$	\mathcal{D}_d	$\varepsilon \mathcal{D}_d^2(\%)$
Muon ($ d > 0.3$)	6.61 ± 0.12	0.473 ± 0.027	1.48 ± 0.17
Electron ($ d > 0.3$)	1.83 ± 0.07	0.341 ± 0.058	0.21 ± 0.07
SVCharge ($ d > 0.3$)	2.77 ± 0.08	0.424 ± 0.048	0.50 ± 0.11
Combined ($ d > 0.3$)	11.14 ± 0.15	0.443 ± 0.022	2.19 ± 0.22
Multidim ($ d > 0.37$)	10.98 ± 0.15	0.395 ± 0.022	1.71 ± 0.19

